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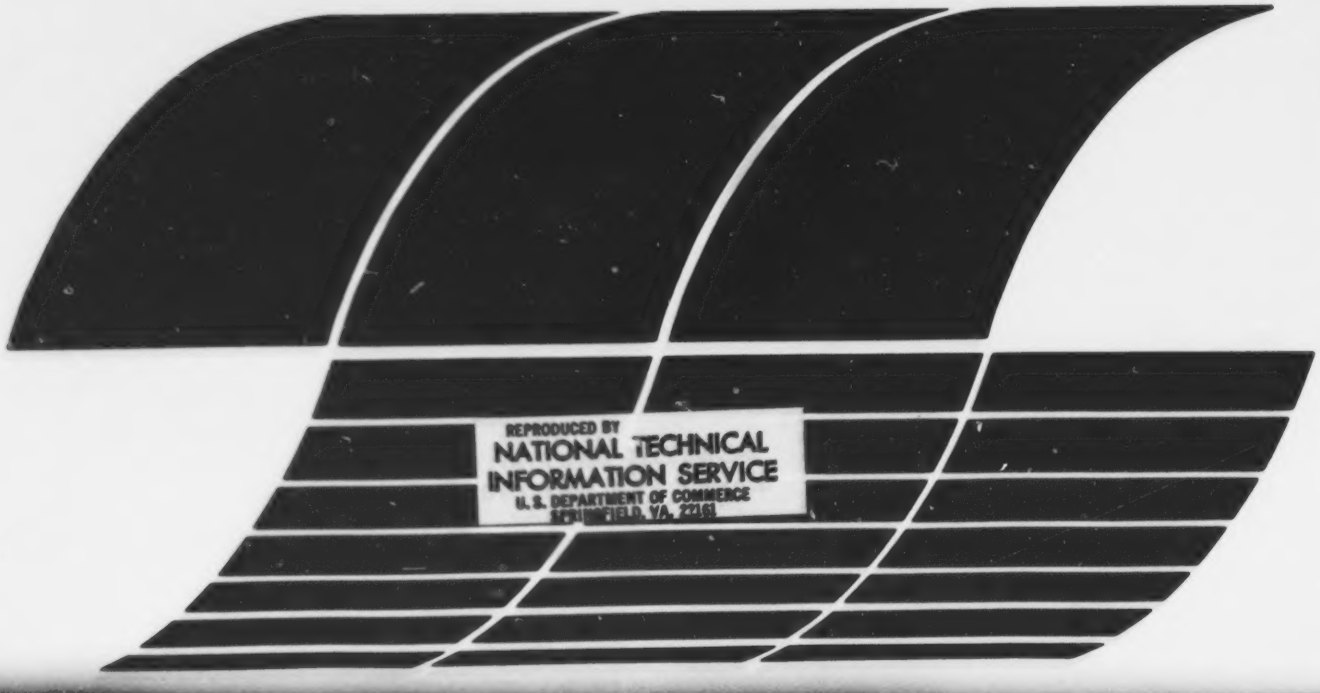

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Trace Element Characterization of Coal Wastes - Second Annual Progress Report

October 1, 1976—September 30, 1977

by

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TRACE ELEMENT CHARACTERIZATION OF COAL WASTES
SECOND ANNUAL REPORT

by

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ABSTRACT

Early in FY 77, we completed the analyses of the trace elements and major minerals in bulk refuse and coal samples from the Illinois Basin. This activity was followed at midyear by studies to elucidate the structural relationships and associations among the trace elements in these materials. Concurrent with these efforts, and continuing throughout most of the year, we conducted several series of weathering and leaching experiments to define the environmental behavior of the trace elements in the refuse and coal samples under various environmental conditions. These investigations resulted in the identification of the trace elements of most environmental concern in typical Illinois Basin refuse and coal. During the latter part of the year, we began to investigate methods to control the trace element contamination of refuse and coal drainage.

EXECUTIVE SUMMARY

This section summarizes some of the technical highlights, evaluations, and recommendations from a Los Alamos Scientific Laboratory (LASL) study of trace element contamination of drainage from coals and coal cleaning wastes. This research has identified those trace elements that are released in hazardous amounts during the weathering and leaching of high-sulfur coal refuse from the Illinois Basin. Control technology strategies to address this problem are discussed. A comprehensive appraisal of the FY 77 programmatic accomplishments is contained in the main body of the report.

The mineral wastes from coal preparation and mine development constitute a major environmental problem. More than 3 billion tons of these materials have accumulated in the U.S., and the current annual rate of waste production of 100 million tons per year is expected to double within a decade. The total number of coal waste dumps is estimated to be between 3000 and 5000, of which half pose some type of health, environmental, or safety problem. Structural weaknesses in coal refuse banks have led to tragic landslides such as those at Buffalo Creek, West Virginia, and Aberfan, Wales, and the approximately 300 burning waste banks are a major source of air pollution. In addition to these problems, there is growing concern about environmental effects from the trace elements present in the highly mineralized acid drainage from coal refuse dumps that affect many thousands of miles of streams and waterways.

Although it has been established that the drainage from coal refuse dumps is often highly contaminated with trace or inorganic elements, little is known about the quantities of undesirable elements released into the environment from this source. Development of the necessary control technologies for human and environmental protection requires quantitative evaluation of the extent and severity of the problem. LASL has been directed by the Department of Energy (DOE) and the Environmental Protection Agency (EPA) to assess the nature and magnitude of trace elements in the effluents from coal preparation wastes (and to a limited extent raw coals), and to identify the technology necessary to control this form of environmental pollution.

The principle objectives of the LASL research program are

- to assess the nature and magnitude of trace elements in the effluents from coals and coal preparation wastes,
- to identify experimentally the chemistry of the trace constituents of environmental concern with the aim of delineating potential removal/recovery systems, and
- to recommend required pollution control technology or necessary RD and D programs.

The researches reported here represent a continuation of the studies begun in FY 76 to establish a firm foundation for subsequent efforts. In this initial period we did the appropriate literature search, developed laboratory and analytical techniques, collected coals and coal waste samples from several parts of the country, and started work on the stated objectives. The following sections summarize the technical highlights, conclusions, and recommendations resulting from this effort to date.

To understand why coals and coal preparation wastes release trace elements (trace elements here are defined as all elements except carbon, hydrogen, sulfur, and oxygen) in the amounts that they do, we have studied the levels and occurrences of these elements in samples of high-sulfur coal cleaning wastes from the Illinois Basin.

Our Illinois Basin refuse samples were composed of clay minerals (illite, kaolinite, and other more complex clays), quartz, pyrite, and marcasite. Interspersed throughout the mineral network were a variety of minor minerals and residual coal. The relative magnitudes of the major minerals constituting these refuse materials did not vary greatly from sample to sample.

Elementally, we found these refuse materials to be very complex. We have identified the presence of some 55 elements in most of the refuse samples and undoubtedly there are more. The most abundant of these elements, iron, aluminum, and silicon, compose the structures of the major mineral systems. The minor elements are present as constituents of minor minerals, components of the residual coal, or substituents in the major mineral lattices.

Our studies of refuse structure and mineralogy delineated the great potential of these materials to release harmful quantities of trace elements. A large number of elements that are generally considered to be environmentally sensitive are present in these refuse materials in significant quantities ($>30\ \mu g/g$). Included among these are fluorine, aluminum, manganese, iron, cobalt, nickel, copper, zinc, arsenic, and lead. Although the relative amounts of some of these components are seemingly small, the absolute quantities that are available in a large or active waste dump could cause grave consequences in the surrounding environment if they were to be released and concentrated by natural processes.

Static and dynamic leaching experiments were performed to evaluate the trace element behavior of Illinois Basin coal wastes under simulated weathering conditions. These experiments were done to provide information needed to predict quantitatively the trace element levels in the drainage from coal refuse dumps or disposal areas and to identify those elements of environmental concern.

Perhaps the single most important characteristic of the high-sulfur refuse materials during aqueous leaching is their pronounced tendency to rapidly produce acidic leachates. This is due to the oxidative degradation of the pyrite and marcasite present in the refuse. Acid formation is partially attenuated by calcite or other neutralizing species in the refuse, but the leachates from the Illinois Basin refuse samples that we studied nearly always had pH values in the range of 2 to 4. These acid leachates are very efficient in dissolving or degrading many of the mineral components of the refuse, thus releasing the trace or minor elements associated with them.

Two types of trace element leachabilities were observed. Because of their abundance in the refuse some elements (such as iron, aluminum, calcium, magnesium) are released in relatively high absolute quantities. Other, less abundant elements (for example, nickel, cobalt, zinc, copper) are leached in a high proportion to the total of each present, although this may not be a large amount in the absolute sense. The first group is highly concentrated in the leachates, the second is highly leachable from the refuse.

Experiments designed to simulate intermittent leaching of high-sulfur coal waste piles were also conducted. These studies revealed that as a result of the rather continuous oxidation of pyrite (and acid formation), intermittently leached refuse dumps pose a far greater pollution threat than those wastes that are always in contact with water or otherwise isolated from air.

The experimental data on trace element leachability that we generated as a result of our simulated weathering and leaching studies were compared with similar data for actual refuse dump drainage from diverse points in the Illinois Basin. The high level of agreement between the two sets of results indicates convincingly that the laboratory leaching tests realistically simulate refuse dump conditions.

The aqueous leachates from the high-sulfur coal and refuse from the Illinois Basin contain a vast array of potentially harmful trace elements. Several toxic elements are consistently present at levels ($>10\ \mu g/m\ell$) that could cause environmental or ecological problems in refuse disposal areas unless some form of effluent control or clean up is exercised. A few other elements, though not present in the refuse leachates in high quantities, have inherently high leachabilities or are associated with labile mineral species, and thus have a significant potential to contaminate refuse drainage under some circumstances.

By assessing our experimental data and using available information on trace element toxicology, we have identified nine elements that have the greatest potential to contaminate drainage or runoff from Illinois Basin coal preparation wastes. These elements appear in the following table along with the criteria by which they were chosen. All of the elements listed in the table are recognized toxicants to plants or animals in quantities comparable to those present in the refuse or refuse leachates. These are the priority elements that should receive the greatest emphasis in subsequent work on environmental control technology.

Despite the thoroughness of the laboratory investigations, it is important when considering the list of elements of environmental concern to bear in mind that almost any designated level of trace elements in a refuse drainage system is somewhat arbitrary from an environmental viewpoint, since the actual harm that toxic elements can cause is a function of the efficiency of accumulation into the surrounding ecosystem. This may depend on factors not directly related to the waste pile, such as volume and dilution of the drainage, and the ability of plants, animals, and soils in the area to concentrate specific toxic elements. Accordingly, the emphasis in our work has been directed at understanding the chemistry and environmental behavior of the trace elements in coal refuse materials to allow us to arrive at technically sound recommendations for those instances where environmental control will prove necessary.

TRACE ELEMENTS OF MOST ENVIRONMENTAL CONCERN IN HIGH-SULFUR ILLINOIS BASIN COAL REFUSE

Element	Labile Mineral Association[a]	High Leachate Concentration[b]	High Inherent Leachability[c]
F	x		
Al		x	
Mn	x	x	x
Fe	x	x	x
Co		x	x
Ni		x	x
Cu		x	x
Zn		x	x
Cd			x

---

[a] Associated with labile minerals (pyrite, marcasite, or calcite) in the refuse samples.

[b] Consistently present in refuse leachates in concentrations exceeding 10 $\mu g/m\ell$.

[c] Consistently leached in amounts exceeding 10 wt% of the total present in the refuse.

Several of the principal conclusions from our work carry implications concerning environmental control strategies.

One of the main implications concerns the importance of pH in determining the levels of trace element contamination in refuse drainage. Throughout our studies, under all conditions of static and dynamic leaching, an inverse relationship prevailed between pH and the amounts of elements leached from the refuse samples. Thus, at low pH (2 to 3), worrisome quantities of trace elements were leached from all of the samples studied; whereas, in those systems where the leachate was more nearly neutral (pH from 5 to 7), trace element leachability and the capability of the leachates to solubilize contaminants were minimized. Therefore, preventing the formation of acids in refuse dumps, or neutralizing the acid drainage as it is formed, should prove effective in controlling trace element releases into the environment.

A related observation from our work concerns the ease with which many of the elements that we have designated as being of environmental concern can be removed from the refuse materials simply by leaching them with aqueous acids. Our environmental studies with Illinois Basin refuse revealed that substantial percentages of the total manganese, cobalt, nickel, zinc, and cadmium available in the refuse materials can be removed by short-term leaching with dilute sulfuric acid. This suggests that many of the environmentally harmful elements in high-sulfur refuse could be removed before disposal by treating the crushed refuse with a dilute acid, and isolating the easily removable elements in the ensuing leachates. This process looks even more attractive when it is considered that the necessary acid could be generated in situ by treating the refuse sulfide constituents with water and air.

Finally, it is quite important to keep in mind, when considering regional control of water pollution from coal waste dumps, that high-sulfur waste materials, which are only intermittently leached by water, generally pose a far greater pollution threat than those that are continuously being leached. Therefore the highest priority and greatest emphasis in pollution abatement programs should be given to those disposal sites that are frequently, but not continuously, in contact with surface or ground water.

It is evident from our studies, and from the available information about actual refuse dump drainage, that further research is needed to identify or assess suitable control technology to prevent environmental degradation by the release of acid and trace elements from some Illinois Basin coal cleaning wastes. Control technology will be necessary both for newly produced coal wastes and for existing refuse dumps. Among the options for preventing the release of trace elements from new refuse materials are immobilization or removal of the elements in question by physical or chemical treatment; reduction of air and water passage through refuse dumps by grading and compacting the refuse as it is disposed, or by the use of sealing agents; prevention of acid build-up in refuse dumps by the addition of neutralizing agents; and, burial of refuse to isolate it from the environment. Methods to treat contaminated drainage from existing refuse dumps include alkaline neutralization, ion exchange, reverse osmosis, and the application of selected adsorbents. A substantial part of our future effort in this program will be directed at identifying the most effective of these options for preventing or controlling trace elements contamination of Illinois Basin coal refuse drainage. Also, to broaden the scope of our work, we will include studies of refuse from the Appalachian and Western coal regions. This investigation will define the potential of the trace elements in these wastes to cause environmental problems, and identify necessary environmental control technology for these materials.

SUMMARY OF TASK PROGRESS

The major objectives of this research program are to assess the potential for environmental pollution from trace or minor elements that are released in the drainages from coal preparation wastes and stored coals, and to identify suitable environmental control measures, if necessary. This report describes technical accomplishments in each of the main research areas of the program for the period October 1, 1976, to September 30, 1977.

The research activities in this program are broken down into major tasks and subtasks, as listed in the Task Breakdown Chart.

TASK BREAKDOWN

TRACE ELEMENTS CHARACTERIZATION AND REMOVAL/RECOVERY

TASK 1	TASK 2	TASK 3	TASK 4
ASSESS THE TRACE ELEMENTS AND MINERALS IN COAL PREPARATION WASTES	DETERMINE THE ENVIRONMENTAL BEHAVIOR OF TRACE ELEMENTS IN COAL WASTES	IDENTIFY TRACE ELEMENTS OF CONCERN IN WASTES AND RECOMMEND POLLUTION CONTROL TECHNOLOGY	ASSESS ENVIRONMENTAL CONTAMINATION FROM TRACE ELEMENTS AND ORGANICS IN STORED COALS
1.1 IDENTIFY TRACE ELEMENTS AND MINERALS IN WASTES	2.1 STUDY WEATHERING AND LEACHING OF TRACE ELEMENTS IN WASTES	3.1 IDENTIFY TRACE ELEMENTS OF ENVIRONMENTAL CONCERN IN REFUSE	4.1 DETERMINE THE TRACE ELEMENTS/ ORGANIC CPDS IN LEACHATES FROM STORED COALS
1.2 DETERMINE RELATIONSHIPS AMONG TRACE ELEMENTS AND MINERALS	2.2 MODEL THE ENVIRONMENTAL BEHAVIOR OF WASTES	3.2 RECOMMEND TECHNOLOGY FOR CONTROLLING TRACE ELEMENT CONTAMINATION	4.2 OBTAIN TRACE COMPONENTS RELEASE RATES FROM COALS
1.3 ESTABLISH MINERALOGY, MORPHOLOGY, AND CHEMISTRY OF TRACE ELEMENTS			4.3 ASSESS THE POTENTIAL FOR ENVIRONMENTAL CONTAMINATION FROM STORED COALS

The objective of Task 1 was to provide an assessment of the identities, structures, and chemistries of the trace elements and minerals in samples of high-sulfur, coal preparation wastes. Accordingly, we completed extensive quantitative analyses of the elemental and mineral compositions of more than 60 refuse samples collected from three coal cleaning plants in the Illinois Basin. These waste materials were found to be composed mainly of clay minerals (illite, kaolinite, and mixed-layer varieties) pyrite, marcasite, and quartz. Smaller amounts of calcite and gypsum were also identified in some of the refuse samples.

The elements present in greatest abundance (usually greater than 1000 μg/g refuse) in the Illinois Basin refuse materials are silicon, aluminum, iron, sodium, potassium, calcium, and magnesium, which are components of the major mineral species. Phosphorus, fluorine, and titanium are also present in significant quantities in these refuse samples. Among the trace elements identified in these wastes, several are present in environmentally disturbing quantities, including manganese, cobalt, nickel, copper, zinc, arsenic, selenium, cadmium, and lead.

Also in Task 1, we conducted an extensive investigation of the structural relationships and associations among the trace elements and major minerals in the Illinois Basin refuse samples. We established structural relationships both by statistical correlation of chemical and physical data, and by direct observation of refuse structure with electron and ion microprobes. The most notable result from the investigation concerned the mineral associations of many of the trace elements that we identified as being highly leachable from the refuse samples and, therefore, of environmental concern. We found that such typical sulfide-forming elements as cobalt, nickel, copper, zinc, and cadmium were not associated with the major pyritic fractions, but rather were constituents of, or embedded in, the refuse clay fractions.

Our efforts in Task 2 were directed at determining the environmental behavior of the trace elements in Illinois Basin refuse samples during weathering and leaching. Both static and dynamic testing were conducted to determine the trace element leachabilities of the various waste samples. In general, the trace elements leached in highest quantities from these samples were iron, aluminum, calcium, magnesium, and sodium, which are constituents of the major refuse minerals. Several elements, while not present in the leachates in large amounts, were nonetheless found to be very easily removed from the refuse materials during aqueous leaching. This group included cobalt, nickel, zinc, cadmium, and manganese.

The highest degree of trace element leachability occurred in waste samples that produced the most highly acidic leachates. Therefore, the largest reductions in the quantities of trace elements released from Illinois Basin wastes were accomplished by keeping the pH of the leachates approximately 7 or higher. Lesser, but significant reductions in acid formation were achieved by increasing the sizes of the refuse particles, reducing the temperature of the system, and limiting the access of air.

One of the objectives of Task 3 was to interpret the information and experimental results obtained in the study, and to identify from them the most environmentally worrisome trace elements in typical Illinois Basin coal preparation wastes. Based on our studies of refuse mineralogy and environmental behavior, we identified fluorine, aluminum, manganese, iron, cobalt, nickel, copper, zinc, and cadmium as being the elements of most concern in cleaning wastes from the Illinois Basin. These elements were chosen because they are often toxic in aqueous systems or soils, and because they are present in the refuse materials in a highly leachable state, or are associated with a labile mineral component of the refuse structure.

Also in Task 3, we began to evaluate several techniques to control acidity and trace elements in the drainage or runoff from coal refuse dumps. Initially, we are considering such methods as alkaline neutralization, ion exchange, reverse osmosis, and flash distillation, which are being used or tested for control of acid drainage from coal mines and refuse dumps. Results from these experiments will be reported during FY 78.

Finally, in Task 4, we investigated the potential for environmental contamination from the trace elements and organic compounds that are released during the weathering and leaching of stored coals. We made extensive use of static and dynamic leaching tests to investigate the environmental behavior of samples of a high-sulfur Illinois Basin coal. The types and quantities of trace elements released from the coal during aqueous leaching are nearly identical to those released from the Illinois Basin cleaning wastes. Iron, aluminum, manganese, cobalt, nickel, zinc, copper, and cadmium were identified as the trace elements most likely to cause environmental problems in the drainages from this type of coal.

The levels of organic contaminants in the coal leachates were determined to be in the range 5 to 50 ppm. A preliminary mass-spectral analysis of this material suggests that it is composed mainly of aliphatic and alicyclic compounds that often contain nitrogen, oxygen, and sulfur functional groups. No direct evidence was obtained for the presence of aromatic or phenolic components in the organic fractions of the coal leachates.

TASK PROGRESS DESCRIPTION

TASK 1—ASSESS THE STRUCTURE AND CHEMISTRY OF TRACE ELEMENTS AND MINERALS IN COAL CLEANING WASTES

The purpose of this task was to provide a comprehensive assessment of the identities, structures, and chemistry of the trace elements and minerals in refuse and coal samples collected from several coal preparation plants in the Illinois Basin. This information was used to support work throughout the year on trace element environmental behavior and removal/recovery technology.

Subtask 1.1—Identify the Trace Elements and Major Minerals in Bulk Waste Materials

During FY 77, we completed the quantitative analysis of the mineral compositions of refuse samples collected from three Illinois Basin coal cleaning plants, where they were produced from the physical cleaning of several of the major types of high-sulfur coals. Descriptions and details of the origins of these samples appear in our FY 76 annual report (EPA-600/7-78-028). Accurate information on the mineral compositions of the refuse materials is necessary to establish trace element/mineral correlations, and to understand behavior of the elements during weathering and leaching.

The mineral compositions of the bulk Illinois Basin refuse samples were determined by x-ray diffraction according to the procedure detailed in Appendix A. A series of pure mineral standards was used to calibrate the x-ray diffractometer and calibration curves were constructed for each of the standards to relate diffractometer response (x-ray peak height) to mineral concentrations. These calibration plots (shown in Progress Report No. 5, LA-6933-PR) are relatively linear over the range of concentrations likely to be encountered. Exceptions to this are pyrite and marcasite, whose calibration curves deviated considerably from linearity above concentrations of 30 wt%. This behavior, we think, is due either to background fluorescence of the iron in these materials, or to particle orientation effects in the sample holder. Both the pyrite and marcasite calibration curves were straightened by using an internal standard and applying the following equation.

$$PH_{FeS_2(\mathrm{corr})} = PH_{FeS_2(\mathrm{meas})} \frac{PH_{Al_2O_3(FeS_2\ \mathrm{absent})}}{PH_{Al_2O_3(FeS_2\ \mathrm{in\ sample})}} ,$$

where PH = peak height.

With the exception of calcite, calibration curves were constructed for at least two x-ray bands for each mineral component. This was done to increase the precision of the mineralogical analyses of the coal and waste samples. Many variables, including sample composition, preparation procedure, orientation effects, and band overlapping, can affect the intensities and exact positions of the individual x-ray bands, making quantitative analyses based only on a single band for each mineral somewhat tenuous. A compilation of the positions and relative intensities of the 2θ bands that we used to characterize the various coal-related minerals is given in Table I. In general, these values compare well with similar data from the literature.

The quantitative mineralogical analyses of approximately 45 refuse samples or fractions therefrom were completed by the XRD technique. The results of these voluminous analyses are reported in their entirety in Appendixes B, C, and D. A summation of these results is given in Table II, which lists the average major mineral compositions of the refuse samples collected from each of the three Illinois Basin preparation plants. These data are based on a minimum of three replicate analyses of each sample. The refuse analyses were done on the as-received material, so only about 80 to 95% of the total was identifiable by the XRD method. The remaining or unanalyzed part of the samples represents residual coal, amorphous mineral matter, and minor mineral species in undetectable amounts.

As is usual for Illinois Basin coals, these refuse samples are composed mainly of clay minerals: illite, kaolinite, and other more complex clays. Quartz, pyrite, and marcasite account for most of the remaining material. Lesser amounts of calcite and gypsum were also identified in some of the samples. The XRD analyses show that variations do occur in the mineral compositions of the refuse materials from the various plants. For example, the total amount of analyzable pyrite and marcasite in the refuse from Plant A averages about 22 wt%, whereas the iron sulfide contents of the Plants B and C refuse were 26 and 30 wt%. Such variation in refuse composition results from geological differences in the character of the mine floor and roof material and of the coal seams supplying the feed coal, and are not unexpected. The relative magnitude of each mineral species or class, however, appears to be fairly fixed. The clay minerals are always predominant relative to the amounts of quartz, pyrite, and marcasite, and these in turn do not vary greatly relative to each other. The exception is calcite, which was found in widely varying amounts in these refuse samples.

Also during FY 77, we completed an extensive analysis of the elemental compositions of the refuse samples collected from the Illinois Basin cleaning plants. These analyses established the levels of the various toxic trace elements in the refuse materials, thus revealing the overall potential of trace element contamination of water.

A description of the analytical methods and techniques used for refuse elemental analyses is given in our FY 76 annual report. Neutron activation analysis (NAA) was used extensively because the refuse materials can be analyzed directly with a minimum of sample preparation, and the concentrations of many elements can be determined simultaneously. Trace elements not readily determined by NAA were analyzed with atomic absorption spectrophotometry, optical emission spectroscopy, or wet chemical methods.

In all, the trace elements in more than 70 refuse samples or increments were analyzed during the year. In each case the concentrations of up to 55 elements were determined. The results of these analyses appear along with the refuse mineral data in Appendixes B, C and D. Listings of the averages, extremes in elemental compositions, and relative standard deviations (RSD) for the

TABLE I

TWO-THETA BAND POSITIONS AND RELATIVE PEAK INTENSITIES OF XRD MINERAL STANDARDS

Mineral	2θ Band (Degrees)	Relative Intensity[a]
Alumina	43.4	1.1
Calcite	30.0	4.4
Gypsum	12.1	3.0
	29.4	2.2
Illite	8.9	0.30
	20.0	0.15
	26.8	0.24
Kaolinite	12.4	1.3
	20.2	0.31
	24.9	1.0
Magnesium Oxide	43.0	2.8
Marcasite	33.4	1.1
	52.2	0.48
Montmorillonite[b]	5.8	0.90
	20.2	0.22
Pyrite	33.1	1.4
	40.7	0.55
	56.2	1.0
Quartz	20.8	0.66
	26.7	3.6

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[a] Based on the 26.7° 2θ band of quartz having an intensity of 3.6.

[b] Glycolated.

refuse samples collected from each of the three Illinois Basin coal preparation plants appear in Tables III through V. These values, we feel, are representative of the elemental compositions of the major types of high-sulfur coal cleaning wastes now produced in the Illinois Basin.

The elements present in greatest abundance in these refuse materials make up the structures of the major minerals, namely, silicon, sulfur, aluminum, iron, sodium, potassium, calcium, and

TABLE II

MAJOR MINERALS IN REFUSE FROM ILLINOIS BASIN COAL PREPARATION PLANTS A, B, AND C

Mineral	Plant A Average - Wt. %	Plant B Average - Wt. %	Plant C Average - Wt. %
Kaolinite	15	7	14
Illite	14	11	16
Other clays	7	17	8
Pyrite	14	15	21
Marcasite	8	11	9
Quartz	22	17	23
Calcite	6	0	1
Gypsum	3	1	1
Other	11	21	7

TABLE III

TRACE ELEMENT COMPOSITION OF REFUSE FROM ILLINOIS BASIN COAL PREPARATION PLANT A[a]

Element[b]	Low	High	Mean	Sigma	RSD[c]
Li	36	59	51	9	0.18
B	54	70	62	7	0.11
F	400	733	630	137	0.22
Na(%)	0.10	0.12	0.11	0.01	0.09
Mg(%)	0.34	0.51	0.41	0.07	0.17
Al(%)	6.5	7.4	7.0	0.4	0.06
Si(%)	13.14	16.4	14.32	1.4	0.10
P	1100	3300	2340	792	0.34
S(%)	6.6	10.8	9.1	1.7	0.19
Cl	20	37	30	9	0.30
K(%)	1.04	1.33	1.15	0.12	0.10
Ca(%)	2.41	6.31	4.06	1.54	0.38
Sc	11.2	13.4	12.2	1.0	0.08
Ti(%)	0.42	0.50	0.46	0.03	0.07
V	72	87	78	6	0.08
Cr	52	70	60	8	0.13
Mn	234	419	301	76	0.25
Fe(%)	6.2	9.4	8.0	1.3	0.16
Co	18	20	19	1	0.05
Ni	37	50	44	5	0.11
Cu	51	55	52	2	0.04
Zn	74	93	83	9	0.11
Ga	16	23	19	3	0.16
Ge	3.9	7.6	5.1	0.6	0.13
As	50	65	56	7	0.12
Se	6.5	11	9.3	1.9	0.20

TABLE III (Cont.)

Element[b]	Low	High	Mean	Sigma	RSD[c]
Y	30	40	35	5	0.14
Zr	130	160	150	14	0.09
Mo	8.1	16	12.2	3	0.02
Cd	0.16	0.30	0.24	0.06	0.25
Sn	< 8	< 9	< 9	-	-
Sb	1.4	1.5	1.5	0.1	0.07
Cs	4.5	7.1	6.2	1	0.02
La	41	49	45	3	0.07
Ce	83	100	92	7	0.08
Sm	6.8	8.1	7.4	0.5	0.07
Eu	1.3	1.7	1.6	0.2	0.12
Dy	5.8	7.3	6.4	0.6	0.09
Yb	2.4	3.7	3.1	0.5	0.16
Lu	0.4	0.5	0.4	0.06	0.15
Hf	3.0	3.7	3.4	0.3	0.09
Ta	< 1	3	1	-	-
Pb	38	60	49	8	0.16
Th	11.5	13.2	12.2	0.8	0.06
U	4.6	8.2	6.8	1.3	0.19
				Av.	0.14

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[a] Analyses include samples No. 10, 11, 12, 25, and 28.

[b] Elemental compositions reported as μg/g of refuse unless otherwise noted.

[c] Relative standard deviation.

TABLE IV

TRACE ELEMENT COMPOSITION OF REFUSE FROM ILLINOIS BASIN COAL PREPARATION PLANT B[a]

Element[b]	Low	High	Mean	Sigma	RSD[c]
Li	47	58	52	6	0.11
Be	2.4	3.1	2.8	0.4	0.14
B	63	65	64	1	0.02
F	346	410	374	33	0.09
Na(%)	0.07	0.09	0.08	0.01	0.12
Mg(%)	.21	.31	.26	0.05	0.19
Al(%)	4.94	5.29	5.09	0.2	0.04
Si(%)	12.90	14.60	13.57	0.9	0.07
S(%)	11.4	14.7	13.5	1.8	0.13
Cl	42	76	57	17	0.30
K(%)	1.07	1.21	1.12	0.08	0.07
Ca(%)	0.09	0.13	0.11	0.02	0.18
Sc	11	13	12	1	0.08
Ti(%)	0.33	0.36	0.35	0.02	0.06
V	78	95	86	9	0.10
Cr	56	72	62	9	0.14
Mn	130	160	144	15	0.10
Fe(%)	9.3	12.8	11	1.8	0.16
Co	25	35	30	5	0.17
Ni	68	73	71	3	0.04
Cu	32.4	38.8	35.4	3	0.08
Zn	117	197	149	42	0.28
Ge	< 8	< 8	< 8	-	-
As	64	130	94	33	0.35
Se	4.8	8	6.2	1.6	0.26
Br	2	2	2	-	-
Rb	81	110	96	15	0.16

TABLE IV (Cont.)

Element[b]	Low	High	Mean	Sigma	RSD[c]
Y	15	21	17.7	3.1	0.18
Zr	80	100	87	11	0.13
Mo	47	57	52	5	0.10
Ag	0.4	0.6	0.5	0.1	0.20
Cd	0.35	0.5	0.4	0.08	0.20
Sn	< 8	< 8	< 8	-	-
Sb	1.1	1.7	1.4	0.3	0.21
Cs	5.8	7.1	6.6	0.7	0.11
La	31	41	37	6	0.16
Ce	61	88	73	14	0.19
Sm	4.8	7	5.9	1.1	0.19
Eu	1	1.4	1.2	0.2	0.17
Dy	4.3	4.4	4.4	0.1	0.02
Yb	2.5	4.4	3.2	1.0	0.31
Lu	0.37	0.47	0.41	0.06	0.15
Hf	2.4	3.7	3.1	0.7	0.22
Ta	0.8	1.1	0.9	0.2	0.22
Pb	31	36	34	3	0.09
Th	8.4	11	9.5	1.3	0.14
U	2.7	2.7	2.7	-	-
				Av.	0.15

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[a] Analyses include samples 17, 23, and 24.

[b] Elemental compositions reported as μg/g of refuse unless otherwise noted.

[c] Relative standard deviation.

TABLE V

TRACE ELEMENT COMPOSITION OF REFUSE FROM ILLINOIS BASIN COAL PREPARATION PLANT C[a]

Element[b]	Low	High	Mean	Sigma	RSD[c]
Li	7	22	14.8	5.5	0.37
B	68	87	79	7	0.09
F	936	1670	1257	345	0.27
Na(%)	0.26	0.37	0.30	0.04	0.13
Mg(%)	0.22	0.40	0.32	0.07	0.22
Al(%)	6.10	8.70	7.36	1.11	0.15
Si(%)	15.06	17.40	16.21	1.06	0.06
P	2700	7300	4580	1979	0.43
S(%)	4.9	15.1	11.6	2.7	0.23
Cl	86	170	109	36	0.33
K(%)	0.99	1.64	1.39	0.26	0.19
Ca(%)	1.02	1.71	1.44	0.26	0.18
Sc	10.4	12.4	11.2	0.9	0.08
Ti(%)	0.40	0.54	0.46	0.05	0.11
V	62	85	73	10	0.14
Cr	60	80	69	9	0.13
Mn	101	162	132	24	0.18
Fe(%)	6.6	10.2	9.2	1.6	0.17
Co	21	32	27	5	0.19
Ni	41	80	59	18	0.30
Cu	27	44	39	7	0.18
Zn	57	228	125	70	0.56
Ga	14	21	17	3	0.18
Ge	4.2	6.4	5.4	0.9	0.17
As	18	26	22	3	0.14
Se	6.5	9.6	8.3	1.4	0.17
Rb	210	300	258	33	0.13

TABLE V (Cont.)

Element[b]	Low	High	Mean	Sigma	RSD[c]
Y	24	32	28	3	0.11
Zr	120	130	126	5	0.04
Mo	8.1	14.0	12.4	2.5	0.20
Cd	0.51	1.50	1.12	0.37	0.33
Sn	< 8	< 9	< 9	-	-
Sb	0.9	1.3	1.1	0.2	0.18
Cs	6.7	9.1	8.0	1.0	0.12
La	39	56	45	7	0.16
Ce	76	100	89	10	0.11
Sm	6.1	8.8	7.2	1.0	0.14
Eu	1.4	1.6	1.5	0.1	0.06
Dy	4.7	6.3	5.4	0.7	0.13
Yb	1.8	3.7	2.4	0.8	0.33
Lu	0.3	0.4	0.4	0.1	0.15
Hf	3.3	4.6	3.9	0.5	0.13
Ta	0.9	1.2	1.0	0.2	0.20
Pb	33	59	50	10	0.20
Th	10.0	13.8	12.1	1.7	0.14
U	5.7	12.9	8.3	3.1	0.37
				Av.	0.19

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[a] Analyses include samples 18, 19, 20, 21, and 22.

[b] Elemental compositions reported as μg/g refuse unless otherwise noted.

[c] Relative standard deviation.

magnesium. Phosphorus and titanium, not components of the major minerals per se, are also present in significant quantities. Among the less abundant elements present in environmentally disturbing concentrations are manganese, cobalt, nickel, copper, zinc, arsenic, selenium, yttrium, cadmium, and lead. Later in this report, we will present experimental evidence that several of these elements are indeed released into the aqueous environment in worrisome quantities by refuse dump weathering and leaching.

Subtask 1.2—Determine the Structural Relationships and Associations Among Trace Elements and Major Minerals in Coal Wastes

During the year we conducted research designed to clarify some of the physical associations or relationships among the trace elements and major minerals in the Illinois Basin refuse materials. Two basic approaches were used to achieve this end: statistical correlations and direct observation. In the first, we used specially designed computer programs to statistically correlate similarities in behavior among the various trace elements and minerals when the refuse samples were subjected to chemical or physical processes. The second approach to understanding the trace element mineralogy of the coal refuse samples involved direct observation of the elemental composition of the microstructures of these materials with electron and ion microprobes and scanning electron microscopes (SEM). The information gained in this subtask was used as a basis for interpreting and understanding the release behavior of trace elements during refuse weathering and leaching.

The behavior correlation method was applied to various samples of refuse collected from each of the three Illinois Basin cleaning plants and to refuse fractions that had been separated on the basis of particle size or density. We expected that trace elements intimately associated with one another in the bulk refuse structure would be nearly identically distributed among the various refuse fractions.

We used the statistical method to relate trace element and mineral data. To quantify the relationships among the various elements in the refuse fractions, we used a computer program to calculate Pearson's correlation coefficients for each of the elements studied (see *Statistical Package for Social Sciences*, Second Ed., by Nie et al., published by McGraw-Hill Book Co., New York, 1975, for details of the calculations). These coefficients range on a scale from +1 among elements present in exactly the same relative amounts in each of the waste fractions to −1 for elements that exhibit exactly inverse behaviors. Intermediate values of the coefficients among elements indicate, of course, varying degrees of similarities or differences in the manner in which the elements are distributed in the waste fractions.

To make any sense of this massive volume of correlation coefficients, however, data must be arranged into groups of elements having similar coefficients. This was accomplished by using sorting methods to cluster the data in conjunction with computer graphic techniques (see Appendix E).

An example of the output from such manipulations is shown in Fig. 1 for the sized refuse samples from Plant B. This chart presents both the values for the correlation coefficients among the various elements, and the clusters or groupings of elements according to these values. The relationships among the elements and such experimental parameters as low-temperature ash (LTA), high-temperature ash (HTA), and the various mineral phases are also included. The values of the correlation coefficients among the elements are denoted by various shadings indicated by the key at the right of the figure. The highly positive coefficients are designated by a black background with varying degrees of white superimposed, and the more highly negative coefficients by a basic white background with black superimposed. The correlation coefficients in

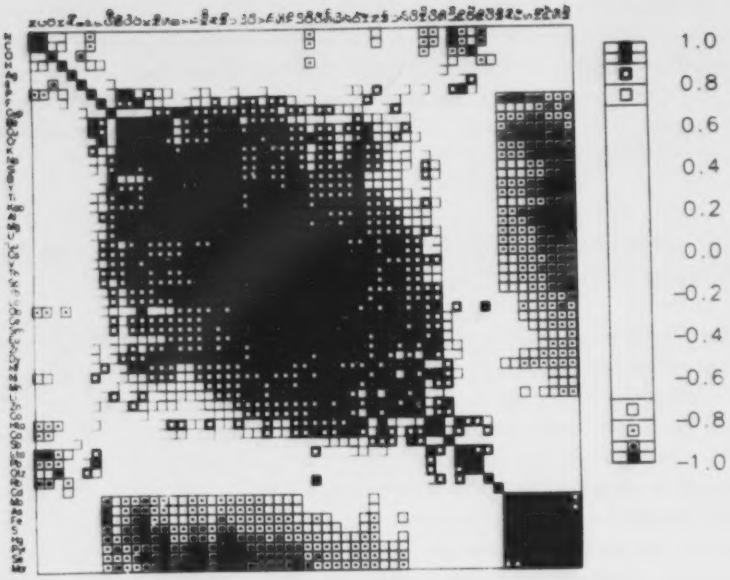

Fig. 1.

Trace element correlation coefficients for sized refuse fractions from cleaning plant B (samples 24b-f).

the range of about −0.7 to +0.7 are less meaningful in terms of interpreting trace element associations, and are left blank.

The clustering or grouping of elements or entities with like correlation coefficients is apparent from Fig. 1. Clusters of elements with highly positive correlation coefficients (> 0.7) signifying a high degree of mutual association in the sized refuse samples, are positioned along the upper left to lower right diagonal of the figure. The clusters of highly negative correlation coefficients, which almost certainly indicates that these elements are not associated in the refuse material, appear in this example along the lower and right edges of the chart.

This method of displaying the correlation data allows a rapid, visual interpretation of associations based on similarities or differences in elemental behavior to be made. For example, in Fig. 1, three distinct groupings of elements that are highly associated with one another can be defined. The largest of these, located near the center of the chart and encompassing the minerals and elements from beryllium through cobalt, includes silicon, aluminum, and most of the other silicate-forming or lithophile elements. In the lower right and the upper left of the graph are two smaller highly associated groupings; one contains iron and sulfur and several other sulfide-forming or chalcophile elements, and the other contains carbon, hydrogen, and nitrogen, which normally are organically associated elements.

For two or more elements to be structurally associated or related in the refuse sample, they must consistently behave alike when the refuse samples are subjected to various types of transformations. It is possible in any single event that factors other than a common structural origin (such as sample inhomogeneity) could cause some of the elements to behave in an apparently similar manner. Therefore, structural relationships among the refuse components based on similarities in behavior can be established only after they have been substantiated in a number of different ways.

Accordingly, we have calculated and grouped the correlation coefficients for the as-collected coal and refuse fractions from cleaning plants A, B, and C, and for refuse fractions from these three plants that had been separated both according to density and particle sizes.* Descriptions of the samples involved and the trace element and mineral analyses for these samples appear in Appendixes B, C, and D, and the cluster plots of the correlation coefficients appear in Appendix E.

To aid in the interpretation of the rather massive amount of data in Appendix E, we have condensed the information from the trace element-mineral correlations for each coal preparation plant and have presented it here as Tables VI, VII, and VIII. The tables contain only the groupings of elements and minerals for each plant that were highly correlated ($R > 0.7$) in all the samples studied. We must emphasize that these data reveal only the groups of trace elements and minerals that reside together in the refuse samples in a physical or spatial sense. This information does not provide the basis for defining the chemical or mineralogical state of the various elements.

The data presented in Tables VI, VII, and VIII largely reflect anticipated differences among the various mineral phases in the refuse from each plant. The clay and quartz fractions contain mainly the lithophile or silicate-forming elements such as aluminum, silicon, sodium, and potassium, and many of the rare earth elements. The iron sulfides (pyrite and marcasite), surprisingly, were relatively free of trace constituents. Only molybdenum was highly associated with the pyritic fractions of the refuse from all plants, and arsenic and selenium were allied with pyrite or marcasite in one or two plants. Similarly, calcium and manganese were the only elements consistently present in the calcite fraction of Plant A. Interestingly, in Plant C, we also delineated a small grouping or cluster of elements including phosphorous, which we have tentatively identified as representing apatite or fluorapatite. Uranium was the only element, other than calcium, fluorine, and phosphorus, highly associated with this mineral type. Finally, in addition to the inorganic components, we differentiated a cluster of elements in each refuse type that were attributable to the coal fractions. Carbon, hydrogen, and nitrogen were strongly linked to the carbonaceous matter in each refuse sample, and chlorine, in addition, was associated with the coal fractions of Plant C refuse.

In addition to the above, a glance at Appendix E will reveal that there are many other elements that we could not associate with any identifiable mineral phase by statistical means. Conspicuous among these are several chalcophile elements, such as cobalt, nickel, copper, and zinc, which are most likely to be present in the refuse as sulfide minerals, and might have been expected to correlate strongly with the iron and sulfur group. Our inability to determine the structural origins of such elements is possibly a reflection of areas that cannot be differentiated on the basis of float/sink separation or particle size segregation. This could be a circumstance where an element is a constituent of a very minor or highly dispersed mineral phase, or where an element occurs simultaneously as a component of two or more mineral species.

The second method that we used to gather detail about the elemental and mineral associations in the Illinois Basin refuse samples involved direct microstructural observation with the electron and ion microprobes. For this study, which included refuse from Plants A and B, we used powdered samples that were mounted in epoxy rather than the as-collected materials. This allowed us to examine the structures of a large number of representative mineral phases while keeping the total number of analytical samples to a minimum. The procedure for preparing the samples for microprobe analysis is given in Appendix G.

The goal of our work with the probes was to conduct a survey of the elemental compositions of representative examples of each of the major refuse minerals, to provide useful information on

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*The procedure used to separate the refuse samples according to particle sizes appears in our FY 76 annual report (EPA-600/7-78-028). The analytical scheme for separating the refuse materials on the basis of density is presented as Appendix F in this report.

TABLE VI

STATISTICAL CORRELATION OF TRACE ELEMENT-MINERAL ASSOCIATIONS IN ILLINOIS BASIN COAL REFUSE - PLANT A

Mineral Class	Associated Elements[a]
Clays/Quartz	Na, Al, Si, K, Sc, Ti, V, Cr, Ga, Y, La, Ce, Sm, Eu, Dy, Yb, Lu, Hf, Th
Pyrite/Marcastie	S, Fe, Mo
Calcite	Ca, Mn
Coal	H, C, N

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[a] Data from cluster analyses of elements having correlation coefficients (R) >0.7 in all instances studied.

TABLE VII

STATISTICAL CORRELATION OF TRACE ELEMENT-MINERAL ASSOCIATIONS IN ILLINOIS BASIN COAL REFUSE - PLANT B

Mineral Class	Associated Elements[a]
Clays/Quartz	Li, F, Na, Mg, Al, Si, K, Sc, Ti, V, Y, Zr, Cs, La, Ce, Sm, Dy, Yb, Lu, Hf, Th, U
Pyrite/Marcasite	S, Fe, As, Se, Mo
Coal	H, C, N

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[a] Data from cluster analyses of elements having correlation coefficients (R) >0.7 in all instances studied.

TABLE VIII

STATISTICAL CORRELATION OF TRACE ELEMENT - MINERAL ASSOCIATIONS IN ILLINOIS BASIN COAL REFUSE - PLANT C

Mineral Class	Associated Elements[a]
Clays/Quartz	Na, Mg, Al, Si, K, Sc, Ti, V, Cr, Ga, Rb, Cs, La, Ce, Sm, Eu, Dy, Yb, Lu, Hf, Th
Pyrite/Marcasite	S, Fe, As, Mo
Apatites	F, P, Ca, U
Coal	H, C, N, Cl

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[a] Data from cluster analyses of elements having correlation coefficients (R) >0.7 in all instances studied.

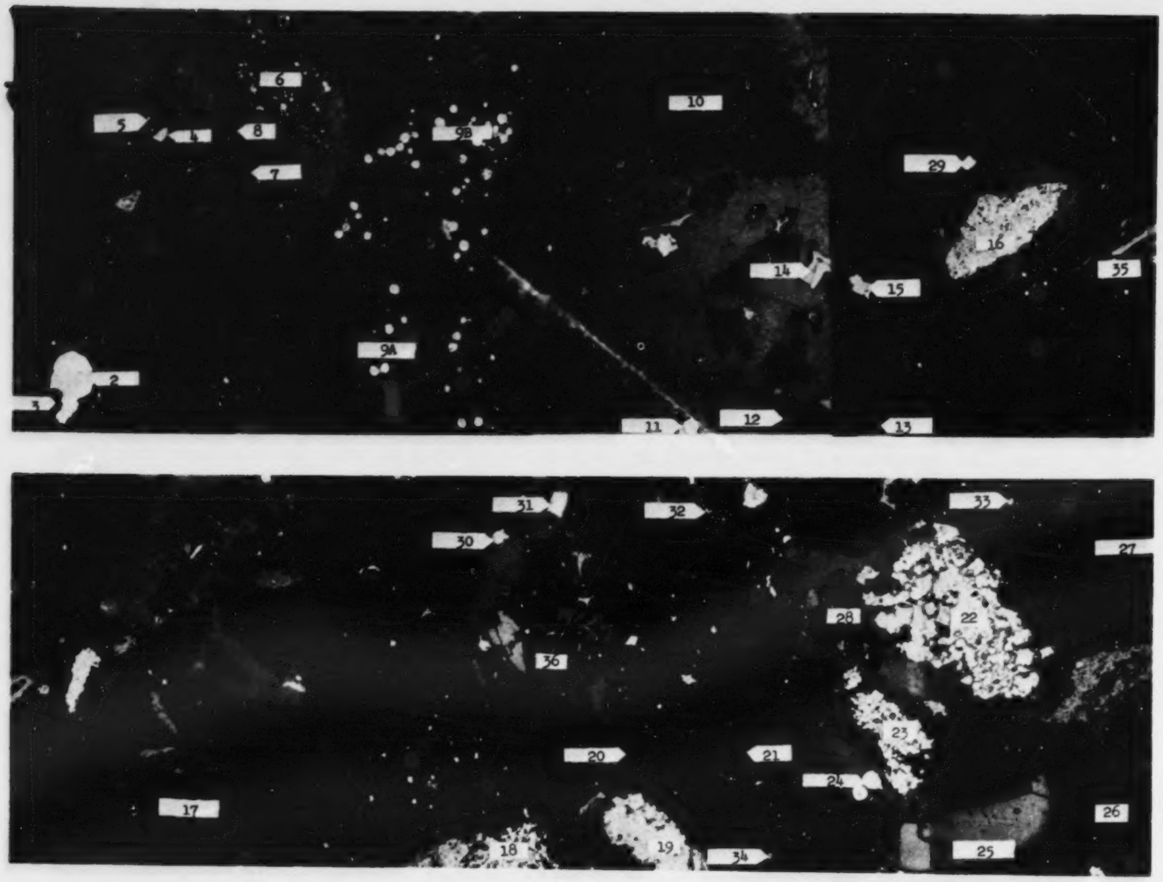

Fig. 2.
Photomicrograph of −20-mesh refuse.

trace-element mineralogy, and to point out which elements were most likely to be associated with labile mineral systems.

Figure 2 is a photomicrograph of one of the Illinois Basin refuse samples that we studied with the microprobes. Although several samples of this kind were examined with the probes, the procedure for this particular one is typical. This analytical sample was prepared from powdered refuse (−20 mesh) that had been mounted in epoxy and polished (and in some areas etched) to reveal the structural detail of the waste material. The various mineral particles or areas that we examined microstructurally in the sample are denoted in Fig. 2 by a numbered bar or arrow. A brief description of each numbered area is given in Table IX. Table IX and Fig. 2 show that many examples of each predominant mineral species in the refuse material were considered. The information gathered from the microprobe analyses of several samples of Illinois Basin refuse similar to that shown in Fig. 2 is summarized in Table X. The terms "abundant" and "occasional" in Table X reflect the relative frequency with which each element was observed in conjunction with the major minerals. The microprobe study revealed, not surprisingly, that the refuse constituents are very finely divided. Thus, areas thought to be relatively pure mineral phases when examined by optical microscopy were shown to be quite impure and heterogeneous when scrutinized by microprobe techniques. It is this fine-grained inhomogeneity which accounts for the varied and often unexpected elemental constituents found in some of the major mineral phases. The clay and coal fractions particularly contain numerous impurities in the form of inclusions and extraneous particles.

Several minor minerals were also detected in the refuse samples. Particles presumed from the elemental analyses to be rutile (TiO_2) and zircon (ZrO_2) were frequently observed in the clay fractions. The occurrence of considerable rutile is not surprising because the titanium content of these wastes is fairly high (0.4 wt%). What are thought to be particles of apatite and fluorapatite were also observed with the probes as constituents of the clay phases. Interestingly, the microprobe analyses of these phosphate minerals showed them to be a source of uranium, thorium, and many of the rare earth elements. Phosphorous also is present in these wastes in relatively high concentrations (~0.3 wt%).

As was also the case for the statistical analyses of trace element-mineral relationships described earlier, during these microprobe studies we were unable to determine the residences of such chalcophile elements as cobalt, nickel, zinc, and copper in the refuse samples considered. This difficulty suggests that these elements are present either as submicron mineral grains or as very dilute polymorphic substituents of the identifiable mineral phases.

The results from the microprobe analyses complement the statistical investigations described earlier. The statistical analyses of refuse trace elements, which are based on much larger and hence more representative samples of the total refuse composition, lack the sensitivity to detect minor mineral phases. Conversely, the microprobe analyses, while limited to a relatively small area of each sample, are much more adept at determining elemental distributions on a microstructural scale.

Subtask 1.3—Establish the Mineralogy, Morphology, and Chemistry of Selected Trace Elements in Coal Refuse

The major concern of this subtask was to gather additional details about the structure and chemistry of a selected group of trace elements that we judged to be of most environmental concern in the Illinois Basin refuse. This information was needed both to better understand the environmental releases of these elements, and, eventually, to aid in choosing suitable environmental control technology. Therefore, we began at midyear to focus on identifying the mineral residences and elemental associations of 13 trace elements (beryllium, aluminum, manganese, iron, cobalt, nickel, copper, zinc, arsenic, selenium, molybdenum, cadmium, and thallium) that had been delineated on the basis of preliminary laboratory leaching studies as being the most environmentally troublesome in the Illinois Basin waste materials. Most of these elements were expected to be present in the refuse in the form of sulfides, and nearly all had been shown by our early environmental studies to be highly leachable from the refuse under typical waste dump conditions.

Based on earlier experiences, we decided that the most rewarding technique for these analyses was the ion microprobe. The statistical studies were useful only to provide information about the

TABLE IX

DESCRIPTIONS OF FEATURES ON PHOTOMICROGRAPHIC MAP[a]

Area No.	Description	Area No.	Description
2	Pyrite - massive, dense	19	Pyrite - massive, porous
3	Quartz - pyrite adhering	20	Quartz
4	Pyrite - massive, dense	21	Quartz
5	Pyrite - framboid	22	Pyrite - massive, porous
6	Pyrite - framboids and small massive	23	Pyrite - massive, porous
7	Quartz - pyrite inclusion	24	Pyrite - framboid
8	Quartz - pyrite inclusion	25	Coal
9	Pyrite - framboids	26	Clay
10	Clay/quartz	27	Clay
11	Pyrite - dense	28	Quartz/coal
12	Quartz	29	Pyrite - massive, dense
13	Coal	30	Pyrite - massive, porous
14	Coal	31	Pyrite - massive, dense
15	Pyrite - massive, dense	32	Pyrite - small massive
16	Pyrite - massive, porous	33	Pyrite - small massive
17	Clay/quartz/coal	34	Pyrite - framboids
18	Pyrite - dendritic	35	Clay
		36	Clay

---

[a] Map is shown in Fig. 2.

TABLE X

TRACE ELEMENT - MINERAL ASSOCIATIONS FROM MICROPROBE ANALYSIS OF ILLINOIS BASIN COAL REFUSE FROM PLANTS A AND B

Mineral	Abundant Elements	Occasional Elements
Iron Sulfides		Tl, Mn, As, Cu
Clays	K, Mg, Ca, Fe, Ti	Li, Rb, Sr, Ba, Cl, Ta, Zr, Ce, La, Nd
Quartz		Li, Be, Na, Mg, Al, K, Ca, Fe, Ta
Oxides	Fe, Ti, Zr, O	Mn, V, Cr
Carbonates		None
Phosphates	Ca, Y, F	La, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Th, U, Ba
Coal	S, O	Li, Na, Mg, Si, Al, K, Ca, Ti, Fe, V, Cr, Mn, Y, La, Ce, Nd, Sm, Eu, Cl

elemental constituents of the major mineral systems, and the electron microprobe, although more highly developed than the ion microprobe method, is limited in sensitivity for most elements to the range of about 100 μg/g. The ion microprobe, on the other hand, is usually sensitive to elemental concentration near 1 μg/g, but interferences among the many elements in the refuse samples had limited the practical usefulness of this technique. Fortunately, we were able to overcome this limitation by using a commercially available computer program to erase mathematically some of the most bothersome interferences from the ion probe spectrum. This routine, called peak stripping, enabled us to gain new insight into the sources and associations of many of the elements.

The results from the ion microprobe analyses of about 50 separate areas in samples of refuse from both plants A and B are given in Tables XI, XII, XIII, and XIV. There is broad agreement between the information displayed in these tables and the trace element/mineral associations identified in the earlier studies. In addition, though, new information was obtained. Foremost was the discovery that several of the chalcophile elements (cobalt, nickel, copper, and zinc) are physically associated with the refuse clay minerals rather than with the iron sulfide systems, where they might have been expected to reside. It is unlikely that these elements are present as parts of the clay mineral structures, but they probably are constituents of separate micromineral phases entrapped within the clay grains.

TABLE XI

ION MICROPROBE OBSERVATION OF TRACE ELEMENTS ASSOCIATED WITH CLAY MINERALS IN ILLINOIS BASIN COAL REFUSE

Associated in More Than 75% of Areas Studied	Observed Occasionally
Lithophile Elements: Na, K, Ca, Mg, Ti, Li, B, F, Cr, Mn, Cs, Ta, U, Ba, Rb, Sr, C	Nb, Cl, Zr, La, Nd, Ce
Chalcophile Elements: Fe, Co, Ni, Cu, Zn	

TABLE XII

ION MICROPROBE OBSERVATION OF TRACE ELEMENTS ASSOCIATED WITH PYRITE AND MARCASITE IN ILLINOIS BASIN COAL REFUSE

Associated in More Than 75% of Areas Studied	Observed Occasionally
Clay Impurities (Al, Si, O, Na, K, Ca, Mg, Ti)	Li, C, F, Cr, Cu, Mo, Tl, As, Mn, Se, Hg

TABLE XIII

ION MICROPROBE OBSERVATION OF TRACE ELEMENTS ASSOCIATED WITH CARBONATES IN ILLINOIS BASIN COAL REFUSE

Associated in More Than 75% of Areas Studied	Observed Occasionally
Clay Impurities (Al, Si, Na, K)	Li, Fe
Mn, Sr, F	

TABLE XIV

ION MICROPROBE OBSERVATION OF TRACE ELEMENTS ASSOCIATED WITH QUARTZ IN ILLINOIS BASIN COAL REFUSE

Associated in More Than 75% of Areas Studied	Occasionally Observed
Clay Impurities (Al, Na, K, Ca, Mg)	Ti, V, Cr, Fe, Co, Ni, Li, Be, Ta
C	

A second observation of note from the ion microprobe studies is that the clay minerals are apparently ubiquitous throughout the refuse structure. Evidences of clay minerals (aluminum, silicon, sodium, potassium, and oxygen) were found in intimate association with every mineral phase studied, including what appeared to be relatively pure pyrite crystals. (This latter observation was substantiated by SEM studies of pyrite framboids that showed what appeared to be lamellar veins of clay dispersed among the individual pyrite crystals.)

A third important observation from the ion microprobe study is the fact that most of the elements of initial environmental concern that we could identify in the refuse materials reside in the clay minerals. Included among these elements are aluminum, manganese, iron, cobalt, nickel, copper, and zinc. Because of the structural complexity of the clay mineral regions and the extreme dilution of many of the toxic trace elements within the clay areas, the chance of rapidly learning very much about the details of the mechanisms governing the aqueous leaching of these elements is quite poor.

As an aid to the assimilation of the rather voluminous amount of information that we have assembled from the statistical and microprobe investigations of Illinois Basin coal refuse, we have attempted to summarize all the data into Table XV. It must be remembered in using the table, however, that there are some very distinct differences in the elemental distributions among the various refuse types studied, and that the information in the table represents only a guide for the likely residences of the trace or minor elements in the refuse samples considered. More accurate information concerning the mineralogical associations for specific elements may be obtained from the data in the foregoing text and the pertinent appendixes.

TABLE XV

SUMMARY OF TRACE ELEMENT - MINERAL ASSOCIATIONS IN REFUSE

FROM THREE ILLINOIS BASIN COAL PREPARATION PLANTS

Element	Mineral Association	Element	Mineral Association
H	coal	Co	clays
Li	clays	Ni	clays
Be	quartz	Cu	clays/pyrite/marcasite
B	clays	Zn	clays
C	coal/carbonates	Ga	clays
N	coal	As	pyrite/marcasite
F	phosphates/carbonates	Se	pyrite/marcasite
Na	clays	Br	coal
Mg	carbonates/clays	Rb	clays
Al	clays	Y	phosphates/clays
Si	quartz/clays	Zr	oxides/clays
P	phosphates	Mo	pyrite/marcasite
S	pyrite/marcasite/gypsum	Cd	clays
Cl	coal/clays	Cs	clays
K	clays	Ba	clays/phosphates
Ca	carbonates/clays/gypsum/phosphates	Rare earths	phosphates/clays
Sc	clays	Hf	clays
Ti	clays/oxides	Ta	clays
V	clays/quartz	Hg	pyrite/marcasite
Cr	clays	Tl	pyrite/marcasite
Mn	clays/carbonates/pyrite/marcasite	Th	phosphates/clays
Fe	pyrite/marcasite/clays/carbonates	U	phosphates/clays

TASK 2—DETERMINE THE ENVIRONMENTAL BEHAVIOR OF TRACE ELEMENTS IN COAL PREPARATION WASTES

The objective of this task was to develop an understanding of the environmental behavior of the trace elements in Illinois Basin coal preparation wastes when they are subjected to conditions encountered during waste dump weathering and leaching. This information was essential in delineating the elements of environmental concern in these wastes.

Subtask 2.1—Laboratory Studies of the Weathering and Leaching of Trace Elements in Coal Wastes

During FY 77, we completed a substantial number of leaching experiments designed to evaluate the environmental behavior of trace elements in samples of refuse collected from three Illinois Basin coal cleaning facilities. Some of these studies were conducted under static or quasi-equilibrium conditions, wherein a known quantity of waste material was allowed to equilibrate with a constant volume of aqueous leachate. Agitation of the sample mixture was provided to promote faster interaction and equilibration between leachates and waste materials. The main advantage of the static/equilibrium experiments was that they were easy to set up and results were quickly obtained; therefore, such studies were ideally suited to rapidly scope the system response to various environmental parameters. A description of the apparatus and experimental procedure for the static/equilibrium leaching method appears in Appendix H.

In addition to the static experiments, we conducted a number of investigations to determine the release behavior of the trace elements in Illinois Basin refuse samples when in contact with flowing leachates. In these experiments, crushed refuse (~1500 g) was packed into a 70-cm-long by 4.6-cm-diam glass column and the leachate, in contrast to the static experiments, was continuously metered through the column. The details of the experimental setup and procedures for the column leaching studies are given in Appendix I. Although these continuous flow experiments were much more difficult and time-consuming, they do represent the actual environmental conditions encountered in refuse dumps much more closely than the static systems. Therefore, we used the static experiments mainly to rapidly scope elemental behavior and the effects of certain variables on refuse/leachate systems. The continuous flow studies served to relate more realistically our laboratory work to a full-scale waste dump.

A composite or average refuse sample from each of the three Illinois Basin coal cleaning plants was used in our initial static leaching experiments. Table XVI is a description of the samples and a listing of their experimental variables. Since the refuse materials from these three plants represent a reasonably broad range of trace element and mineral compositions (see Tables II through V), this series of leaching experiments was suited for determining the overall relationships among refuse bulk mineralogy and trace element releases during aqueous leaching.

For these static experiments, we used refuse samples crushed to −20 mesh to more closely equalize the particle sizes and surface areas of each sample. Each refuse sample (50 g) was agitated with distilled water (250 ml) in an open system for times varying from 1 to 56 days. At the completion of each experiment, the leachates were separated from the residues by vacuum filtration and analyzed. The analytical results, including data on leachate pH, solids contents, and trace element compositions, are reported in Appendix J.

The measured values for leachate pH and total dissolved solids (TDS) at the termination of each experiment are plotted in Fig. 3. These parameters reflect some striking differences in the leaching behavior of each of the three refuse types. With regard to pH, the leachates from Plant B

TABLE XVI

DESCRIPTION OF STATIC LEACHING EXPERIMENTS WITH REFUSE FROM ILLINOIS BASIN CLEANING PLANTS A, B, AND C

Experiments No. GL-22, SGL-5, and GL-21

Leachate No.		Refuse Size	T, °C	Air	Time (Days)
Plant A[a]	1	-20 mesh	22	open	1
	2	-20 mesh	22	open	7
	3	-20 mesh	22	open	28
	4	-20 mesh	22	open	56
Plant B[b]	6	-20 mesh	22	open	1
	12	-20 mesh	22	open	7
	18	-20 mesh	22	open	28
	22	-20 mesh	22	open	56
Plant C[c]	1	-20 mesh	22	open	1
	2	-20 mesh	22	open	7
	3	-20 mesh	22	open	28

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[a] An average of refuse samples 12, 25, and 28 was used in this study.

[b] An average of refuse samples 17, 23, and 24 was used in this investigation.

[c] An average refuse material consisting of sample numbers 18 through 22 was used in this study.

refuse almost immediately became acidic and remained so throughout the duration of the experiment; whereas leachates in contact with Plant A refuse remained essentially neutral throughout the test. Refuse from Plant C exhibited an intermediate acid generating potential. These characteristics undoubtedly reflect differences in the balance between refuse acid-forming constituents (iron sulfides) and basic substances (carbonates). Plant B refuse has a lot of pyrite and marcasite, but contains only negligible amounts of calcite (Table II), which explains its very marked tendency to produce highly acidic leachates. Refuse from Plant A also contains substantial amounts of pyritic minerals, but in addition, apparently contains enough calcite to balance acid formation throughout the experiment. Plant C refuse contains pyrite and marcasite in quantities similar to those found in Plant A and B refuse, but has much less calcite in its structure than Plant A. The small amount of calcite is soon consumed and the leachate becomes more like

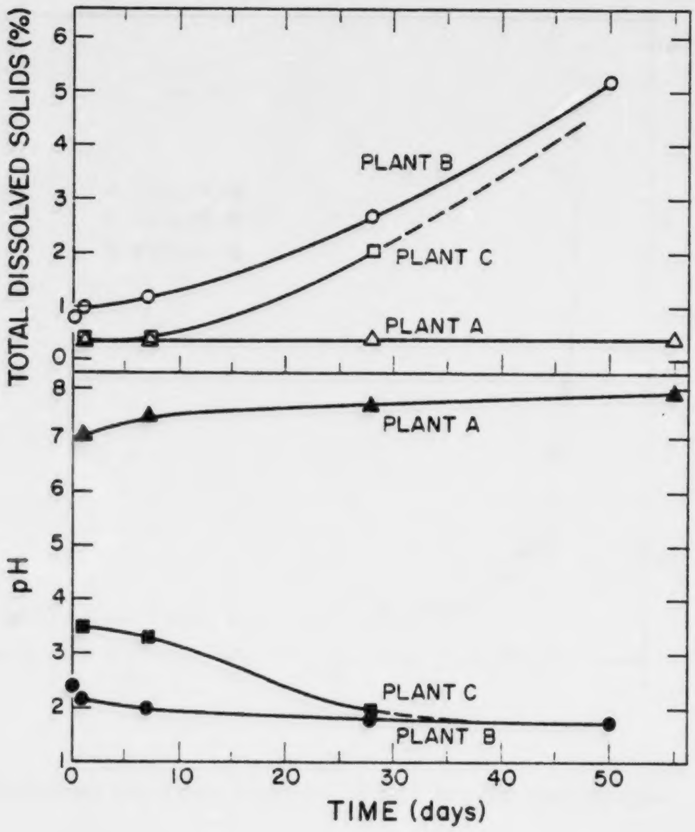

Fig. 3.
Leachate pH and TDS as a function of time from static leaching experiments with refuse from three coal cleaning plants.

that associated with Plant B refuse. The relationship between leachate pH and TDS for the static leachates from the three refuse samples is shown in Fig. 4. In general, where leachate pH is low, TDS values tend to be high, and vice versa. The more highly acidic leachates associated with Plant B refuse were observed to contain from about 1 to more than 5 wt% of dissolved solids depending on the leach duration. By contrast the essentially neutral leachates produced by Plant A refuse were never observed to contain more than 0.4 wt% TDS.

The trace element levels in the various leachates produced during this static leaching study are reported in Appendix J. For the most part, the elements present in the highest concentrations in these leachates (iron, aluminum, calcium, magnesium, and sodium) are the main constituents of the major mineral systems in the refuse. Indeed, the high levels of these trace elements detected in the aqueous leachates from each of the three refuse types indicate that most of the components of the mineral matrixes of the refuse have been affected, though not always extensively.

To help assimilate the vast quantity of trace element data contained in Appendix J, we have tabulated the information for 1 day of leaching into groups according to concentration ranges in Tables XVII through XIX. These tables reflect two important points that may have been difficult to ascertain from the total appendix. First, there is a continuing trend to produce far more highly contaminated solutions when leachate acidity is high. Leaching of refuse from cleaning

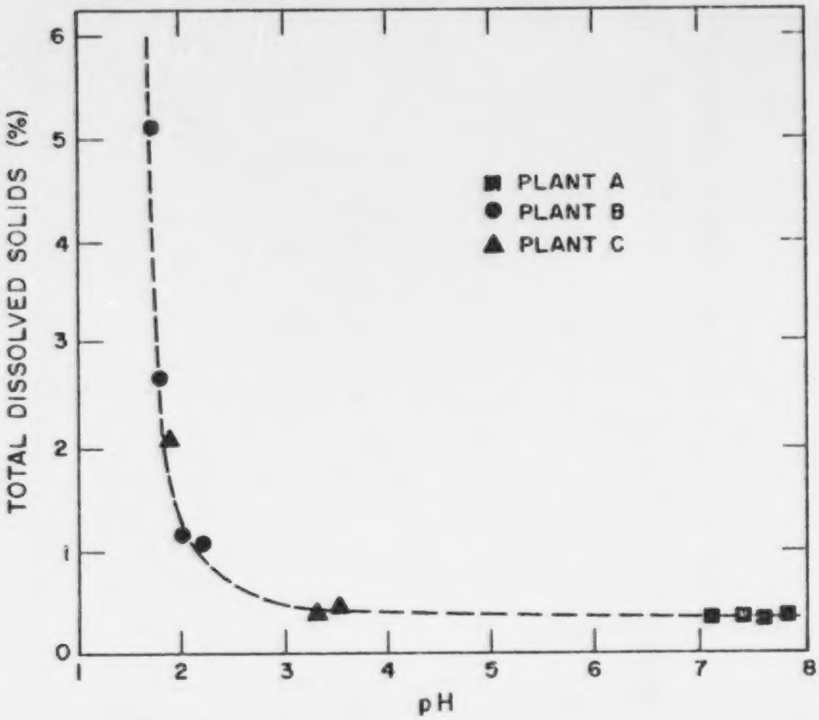

Fig. 4.
The relationship between pH and TDS for leachates from static leaching experiments with coal refuse.

Plants B and C for 1 day produced acidic leachates that removed aluminum, calcium, iron, sodium, magnesium, potassium, manganese, cobalt, nickel, and zinc from the refuse in excess of 10 μg/g of refuse involved. By comparison, the neutral leachates produced by Plant A refuse removed only four elements in excess of 10 μg/g of refuse (calcium, magnesium, potassium, and manganese). The second important observation from these tables concerns the relatively high concentrations of certain environmentally harmful trace elements in the leachates, particularly those associated with the acid refuse samples. Concentrations in excess of 10 μg/g aluminum, iron, manganese, cobalt, nickel, and zinc were observed in the leachates from one or more of the refuse samples. As will be discussed under Task 3, all of these elements are thought to be toxic to certain plants or animals in aqueous systems or soils at levels comparable to those observed in our experimental leachates.

Tables XX through XXII show the 1-day static leaching data as they reflect the percentages of the total of each element available in the refuse leached from the various waste samples. These tables are intended to reveal the elements that are inherently the most labile from the refuse samples during environmental weathering. Here we obtain a slightly different picture of refuse leachability. The overall solubility of the clay minerals and the iron sulfides is relatively low for all three refuse types, because 10% or less of the total aluminum and iron is leached from the samples. (The hydroxides of these ions would be insoluble at pH = 7, but soluble at the pH = 2.2 encountered with Plant B leachate.) Several elements, however, including cobalt, nickel, calcium, zinc, cadmium, magnesium, and manganese, frequently exceed 10% leachability (particularly in the acidic leachates), and are, therefore, environmentally active. Again, several of

TABLE XVII

ELEMENTAL COMPOSITION OF LEACHATES FROM STATIC LEACHING EXPERIMENTS WITH PLANT A ILLINOIS BASIN COAL REFUSE[a]

Experiment No. GL-22

Leachate Concentration, μg/g Refuse[b]	Element
> 500	Ca
100-500	Mg
10-100	K, Mn *
< 10	Na, Al, Sc, V, Cr, Fe, Co, Ni, Cu, Zn, Ga, As, Br, Rb, Ag, Cd, Sb, Cs, La, Ce, Sm, Eu, Dy, Yb, Lu, Hf, Ta, W, Hg, Pb, Th, U

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* Of environmental concern (see Task III).

[a] Conditions: -20 mesh refuse, 1 day, room temperature, unlimited air.

[b] pH = 7.1.

TABLE XVIII

ELEMENTAL COMPOSITION OF LEACHATES FROM STATIC LEACHING EXPERIMENTS WITH PLANT B ILLINOIS BASIN COAL REFUSE

Experiment No. SGL-5[a]

Leachate Concentration, μg/g Refuse[b]	Element
> 500	Ca, Fe*
100-500	Mg, Al*
10-100	Na, Mn*, Co*, Ni*, Zn*
< 10	K, V, Cr, Cu, Cd, Dy, Pb

---

*Of environmental concern. (See Task III.)

[a] Conditions: -20 mesh refuse, 1 day, room temperature, unlimited air.

[b] pH = 2.2.

TABLE XIX

ELEMENTAL COMPOSITION OF LEACHATES FROM STATIC LEACHING EXPERIMENTS WITH PLANT C ILLINOIS BASIN COAL REFUSE

Experiment No. GL-21[a]

Leachate Concentration µg/g Refuse[b]	Element
> 500	Na, Ca, Fe*
100-500	Mg, Al*
10-100	K, Mn*, Co*, Ni*
< 10	Sc, V, Cr, Cu, Zn, Ga, As, Br, Rb, Ag, Cd, Sb, Cs, La, Ce, Sm, Eu, Dy, Yb, Lu, Hf, Ta, W, Hg, Pb, Th, U

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*Of environmental concern (see Task III).

[a] Conditions: -20 mesh refuse, 1 day, unlimited air, room temperature.

[b] pH = 3.5.

TABLE XX

RELEASE PERCENTAGES OF ELEMENTS DURING STATIC LEACHING EXPERIMENTS WITH PLANT A ILLINOIS BASIN COAL REFUSE

Experiment No. GL-22[a]

Percent Leached of Original in Refuse[b]	Element
> 25	
10-25	Co*, Ni*
1-10	Mg, Ca, Mn, Cd
< 1	Na, Al, K, Sc, V, Cr, Fe, Cu, Zn, As, Sb, La, Ce, Sm, Eu, Dy, Hf, Pb, Th, U

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*Of environmental concern (see Task III).

[a] Conditions: -20 mesh refuse, 1 day, room temperature, unlimited air.

[b] pH = 7.1.

TABLE XXI

RELEASE PERCENTAGES OF ELEMENTS DURING STATIC LEACHING EXPERIMENTS WITH PLANT B ILLINOIS BASIN COAL REFUSE

Experiment No. SGL-5[a]

Percent Leached of Original in Refuse[b]	Element
> 25	Ca, Co*, Ni*, Zn*, Cd*
10-25	Mg, Mn*, Dy
1-10	Na, Al, V, Cr, Fe, Cu, Pb
< 1	K

---

*Of environmental concern (see Task III).

[a] Conditions: -20 mesh refuse, 1 day, room temperature, unlimited air.

[b] pH = 2.2.

TABLE XXII

RELEASE PERCENTAGES OF ELEMENTS DURING STATIC LEACHING EXPERIMENTS WITH PLANT C ILLINOIS BASIN COAL REFUSE

Experiment No. GL-21[a]

Percent Leached of Original in Refuse[b]	Element
> 25	Na, Co*
10-25	Ca, Mn*, Ni*, Cd*
1-10	Mg, Sc, Fe, Zn, Ce, Sm, Eu, Dy, Yb, Lu, U, Pb
< 1	K, Al, V, Cr, Cu, Ga, As, La, Ce, Th

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*Of environmental concern (see Task III).

[a] Conditions: -20 mesh refuse, 1 day, room temperature, unlimited air.

[b] pH = 3.5.

these elements are known, under some circumstances, to be harmful in aqueous systems. These observations of trace element leachability demonstrate potential environmental problems that may be caused by refuse dump leaching, and they also suggest possible economical recovery of certain trace constituents.

Additional static leaching experiments (only on Plant B refuse) were run during the year. They were designed to explore the effects of temperature, refuse particle size, and the availability of air on trace element releases during refuse leaching. The experimental conditions used in this leaching study are presented in Table XXIII.

The effects of the experimental variables on leachate pH for the Plant B refuse samples are shown in Fig. 5. All of the leachate pH values, whether for long or short leach times, are quite low. The variables with the most pronounced effect on solution pH are temperature and air availability. Lower leachate pH values are observed for the experiments conducted at 75°C than for those done at ambient temperature. Also the pH values of the leachates from the experiments conducted in open vessels with unlimited access to air are, except for short reaction times, consistently lower than those in closed vessels. Smaller particle sizes give leachates with lower pH values, but size appears less important than temperature or air content. It must be remembered, however, that many waste piles contain particle sizes much larger than those used here.

The TDS values of the leachates from these experiments are also reported in Fig. 5. Not unexpectedly, they follow a pattern nearly inverse to that of leachate pH. Where the pH is relatively low, the TDS in the leachates tend to be high and vice versa. An important point to note is the very high amounts of dissolved materials in all the leachate samples. After only 10 min of contact with the crushed refuse, the aqueous solutions already contain in excess of 0.38 wt% of extraneous material. These values can increase to as much as 5 wt% of TDS after 56 days of leaching time. This is a vivid demonstration of the ability of aqueous acids (acid mine drainage) to dissolve and alter the structure of coal mineral matter.

Before continuing to the other results from these experiments some observations should be made concerning the apparent influences of the various experimental parameters on leachate pH and TDS. To put these observations in perspective, however, it is necessary to realize that the major contributor to solution acidity in the refuse-leachate mixture is the oxidation of pyrite (marcasite) in the presence of air and water to form ferrous sulfate and sulfuric acid. In abbreviated form this reaction is written as

$$FeS_2 + 7/2\ O_2 + H_2 \mid FeSO_4 + H_2SO_4$$

Consider first the effects of oxygen or air content on the pH and TDS of the leachate. In nearly all instances, the pH of the mixtures with free access to air were lower and TDS higher than those contained in air-deficient systems. This can be attributed to the fact that oxygen is a necessary reactant in the acid-formation step. If enough oxygen is available, the generation of sulfuric acid would be expected to continue throughout the leaching period. We believe that the fact that the pH curves, even for the air-rich systems, flatten out with time rather than continue to decrease reflects the development of a bisulfate buffer system ($pK_a = 1.3$) in the leachate rather than a cessation of acid production.

The observation that the effects of refuse surface area were minimal also leads to an interesting possibility. This behavior is characteristic of heterogenous reactions in which the rate-determining step is a diffusion rather than a chemical process. If so, the rate-limiting step for acid formation and solids dissolution in our system involves either the diffusion of reactants to the refuse surface or products away from the surface. This proposition is substantiated by the observance of a rather small temperature effect for pH development. Diffusion-controlled processes generally have relatively low activation energies, although the small temperature dependence

TABLE XXIII

EXPERIMENTAL CONDITIONS USED IN STATIC/EQUILIBRIUM LEACHING STUDY OF ILLINOIS BASIN COAL REFUSE

TIME		10 MIN.		1 DAY			7 DAYS			28 DAYS			56 DAYS		
ATMOSPHERE [(a)]		S		S	0	0	S	0	0	S	0	0		0	
TEMPERATURE, °C		22		22	22	75	22	22	75	22	22	75		22	
GOB SAMPLE	-20 mesh	x[(b)]		x	x	x	x	x	x	x	x	x		x	
	-3/8 in.	x		x	x	x	x	x	x	x	x	x		x	

(a) S = sealed vessel, 0 = open vessel.

(b) The combination of variables studied is designated by an x.

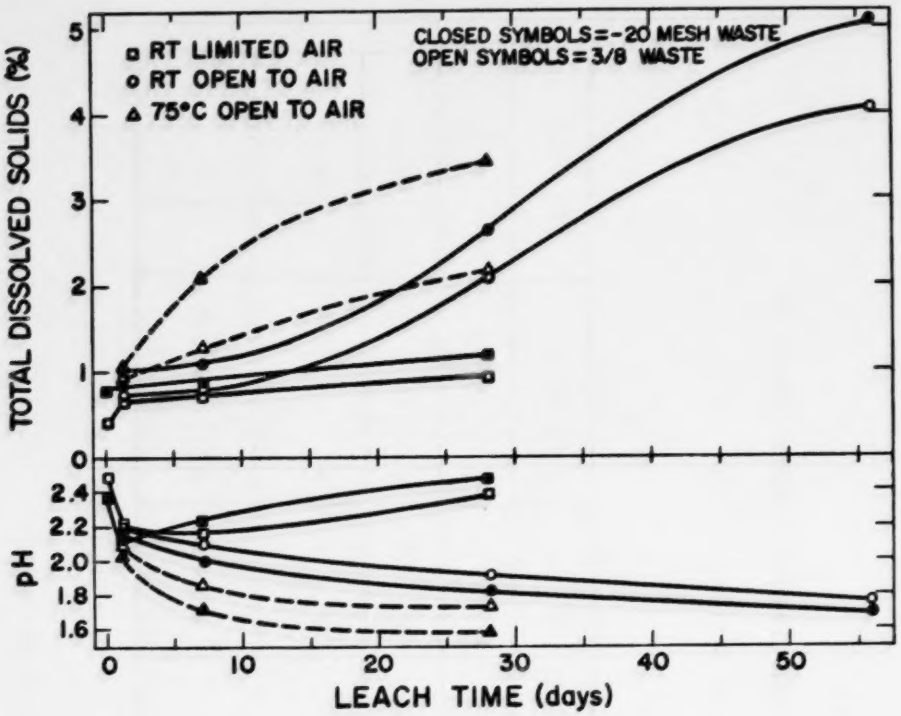

Fig. 5.
Leachate pH values and TDS from static/equilibrium leaching study of coal refuse.

of our system could be partly due to the reduced solubility of oxygen in the leachate at high temperatures.

The trace element data collected from this series of static leaching experiments on Plant B refuse are presented in Appendix K. To illustrate the effects of the experimental parameters on certain trace element releases during refuse leaching we have calculated the release percentages based on the total amounts of those elements available in the refuse samples. This information is presented in Tables XXIV through XXIX.

An inspection of the data in Tables XXIV through XXIX reveals some very interesting facts. Several elements, including iron, calcium, manganese, cobalt, nickel, zinc, and cadmium, are consistently leached in high percentages from the refuse samples under all of the experimental conditions studied. These labile elements (except calcium) share at least one common trait: thermodynamically, all should exhibit a marked tendency to be present in the refuse sulfide minerals. The remaining elements in the tables, aluminum, sodium, potassium, magnesium, chromium, and lead, are much less leachable than the above elements under the experimental conditions. The copper percentages are very erratic. We strongly suspect that copper is sometimes complexing with some other agent in the system.

The experimental variables, particle size, availability of air, and temperature, have only moderate influence over the elemental compositions of the leachates. In most cases, greater amounts of the elements studied are solubilized from the −20-mesh refuse than the corresponding −3/8-in. material (compare Tables XXIV and XXV, XXVIII and XXIX), although refuse particle size has a less notable effect when air is limited (Tables XXVI and XXVII). Also,

TABLE XXIV

STATIC/EQUILIBRIUM LEACHING OF ILLINOIS BASIN COAL WASTE

CONDITIONS: -20 MESH, 22°C, UNLIMITED AIR

Elements Leached (% available in waste)

Leaching Time (days)	Fe	Al	Na	K	Mg	Ca	Cr	Mn	Co	Ni	Cu	Zn	Cd	Pb
10 min.														
1	9.0	1.9	1.3	0.07	12	90	1.0	21	70	46	3	41	50	3
7	9.0	1.8	1.0	0.05	11	84	0.4	22	65	44	3	53	68	2
28	26	2.1	0.20	0.00	11	89	1.1	27	68	50	21	76	76	2
56	46	2.2	0.10	0.01	12	90	1.2	32	70	54	36	100	82	3

TABLE XXV

STATIC/EQUILIBRIUM LEACHING OF ILLINOIS BASIN COAL WASTE

CONDITIONS: -3/8 IN., 22°C, UNLIMITED AIR

Elements Leached (% available in waste)

Leaching Time (days)	Fe	Al	Na	K	Mg	Ca	Cr	Mn	Co	Ni	Cu	Zn	Ce	Pb
10 min.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1	6	0.8	0.9	0.27	8.2	62	0.4	15	50	33	7	26	32	2
7	8	0.6	0.9	0.17	8.6	76	0.5	18	68	39	7	34	40	2
28	20	1.2	1.0	-	10.0	59	0.8	32	66	47	28	44	47	2
56	37	1.7	1.1	0.01	11.5	100	1.0	42	78	60	48	51	58	2

TABLE XXVI

STATIC/EQUILIBRIUM LEACHING OF ILLINOIS BASIN COAL WASTE

CONDITIONS: -20 MESH, 22°C, LIMITED AIR

Elements Leached (% available in waste)

Leaching Time (days)	Fe	Al	Na	K	Mg	Ca	Cr	Mn	Co	Ni	Cu	Zn	Cd	Pb
10 min.	6.7	1.5	0.9	0.29	10	64	0.95	17	56	40	3.5	33	37	4
1	7.5	1.6	0.5	0.11	10	75	1.0	19	61	41	1.2	35	42	11
7	8.3	1.7	1.5	0.64	10	82	0.9	20	59	39	0.1	41	42	2
28	10.0	1.9	3.1	1.82	11	87	1.0	21	60	40	0.3	49	45	4

TABLE XXVII

STATIC/EQUILIBRIUM LEACHING OF ILLINOIS BASIN COAL WASTE

CONDITIONS: -3/8 IN., 22°C, LIMITED AIR

Elements Leached (% available in waste)

Leaching Time(days)	Fe	Al	Na	K	Mg	Ca	Cr	Mn	Co	Ni	Cu	Zn	Cd	Pb
10 min.	3.0	0.78	0.7	0.28	7.4	50	0.3	14	42	30	9.6	22	29	6
1	5.4	1.04	0.9	0.34	9.3	70	0.5	17	61	42	11.7	33	37	3
7	7.1	0.94	0.9	0.31	9.6	66	0.6	20	66	41	2.5	39	40	2
28	10.2	1.07	2.8	1.12	9.5	60	0.7	17	63	36	0.3	57	37	10

TABLE XXVIII

STATIC/EQUILIBRIUM LEACHING OF ILLINOIS BASIN COAL WASTE

CONDITIONS: -20 MESH, 75°C, UNLIMITED AIR

Elements Leached (% available in waste)

Leaching Time(days)	Fe	Al	Na	K	Mg	Ca	Cr	Mn	Co	Ni	Cu	Zn	Cd	Pb
10 min	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1	11	1.8	2.0	0.10	11	90	0.8	22	59	41	0.5	48	74	2
7	21	3.2	3.5	0.15	15	89	2.1	27	55	44	1.7	69	74	3
28	30	5.8	6.1	2.77	20	94	3.7	32	57	49	0.5	96	82	2

TABLE XXIX

STATIC/EQUILIBRIUM LEACHING OF ILLINOIS BASIN COAL WASTE

CONDITIONS: -3/8 IN., 75°C, UNLIMITED AIR

Elements Leached (% available in waste)

Leaching Time (days)	Fe	Al	Na	K	Mg	Ca	Cr	Mn	Co	Ni	Cu	Zn	Cd	Pb
10 min.														
1	8	0.9	0.9	0.29	9	71	0.7	19	62	38	4.3	34	37	3
7	12	1.8	1.8	0.50	13	95	1.1	24	60	46	3.1	46	45	4
28	18	4.1	3.5	0.64	18	100	2.9	37	71	54	7.6	56	53	1

limitation of air to the system reduces the solvating power of the leachates (compare Tables XXIV and XXVI, XXV and XXVII), probably by limiting the acid-forming reactions of pyrite and marcasite. And finally, temperature effects can be seen by comparing the data in Tables XXIV and XXVIII, and XXV and XXIX. Here the results are mixed. Some elements (aluminum, sodium, potassium, and chromium) appear to be more highly leachable at elevated temperature, but most are not affected. This is not an implausible result for the complex kinetic system represented by the refuse leachate mixture.

From our observations of trace element behavior during the static aqueous leaching of Illinois Basin coal refuse, a reduction in both the absolute amounts and percentages of trace elements released from the refuse materials during aqueous leaching under conditions simulating the environmental circumstances in refuse dumps can be obtained by (1) increasing the particle sizes of the crushed refuse to give minimum surface area, (2) reducing the temperature of the system, and (3) limiting access of air to the refuse dump.

With the information from the static/equilibrium leaching studies of the Illinois Basin refuse samples as a guide, we began at midyear, to investigate the leaching behavior of these refuse materials under more dynamic conditions. Water was passed through packed columns of crushed refuse to simulate (more closely than the static studies) aqueous leaching under refuse dump conditions. Table XXX is a listing of the experiments for this series. The trace element analyses for the leachates from these experiments are tabulated in Appendix L.

TABLE XXX

DESCRIPTION OF CONTINUOUS LEACHING STUDIES OF ILLINOIS BASIN COAL REFUSE[a]

Plant	Experiment No.	Refuse Used[b]	Leachate Flow Pattern
A	GL-19	12, 25, 28	Uninterrupted
B	GL-7	17, 23, 24	Uninterrupted
	GL-8	17, 23, 24	Uninterrupted
	GL-9	17, 23, 24	Interrupted at 2.7 ℓ for 1 day and at 8.7 ℓ for 7 days
	GL-10	17, 23, 24	Interrupted at 2.7 ℓ for 1 day and at 8.7 ℓ for 7 days
C	GL-20	18,19,20,21,22	Uninterrupted

---

[a] These experiments were conducted at ambient temperature with 1.5 kg of refuse material crushed to -3/8 in. and packed into a 70-cm-long by 4.6-cm-diam glass column. Leachate (distilled water) flow rate was maintained at 0.5 mℓ/min.

[b] Refuse sample studied was an average of the listed fractions.

Two types of flowing or dynamic leaching experiments were completed with the Illinois Basin refuse samples. In the first we used a continuous leachate flow (30 ml/h) for the duration of the experiment (GL 19, 7, 8, and 20). This condition simulates water continuously passing through the refuse dump, such as for refuse that has been deposited into a swamp or waterway, or where the refuse has been used to impound a slurry pond or as a reservoir dam. In the second type of dynamic leaching experiment, leachate flow was periodically interrupted and a stream of air was blown through the column before flow was restarted (GL 9 and 10). This is more typical of the actual environmental condition of a majority of the waste dumps, where water from rain or some other source only periodically comes in contact with the refuse mass.

The data for pH and total salt content of the leachates collected from the uninterrupted leaching experiments are plotted in Fig. 6. The trends in leachate pH and TDS throughout the experiment are readily apparent. The leachate pH values are initially low and as a greater volume of leachate flows through the refuse column, pH begins to rise and level off. Apparently,

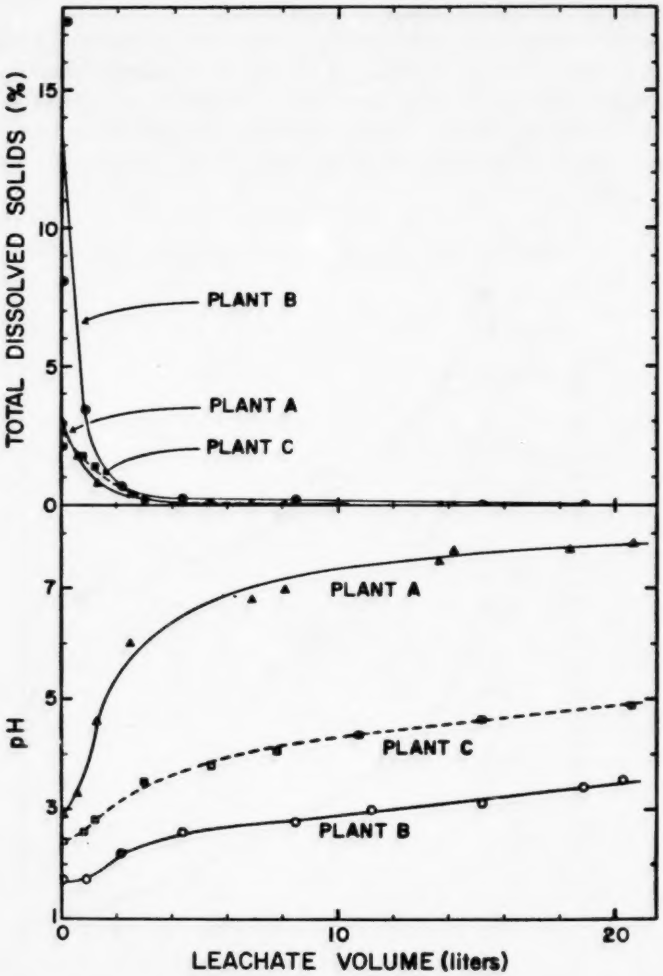

Fig. 6.
Total dissolved salts and pH values for uninterrupted dynamic leaching experiments with refuse from cleaning plants A, B, and C.

this occurs because the acid-forming reactions of pyrite and marcasite are slow relative to the flow of fresh leachate into the system. Alternatively, the trend to increasing pH values may be due to delayed buffering of the leachate acid content by some refuse component. The salt contents of the refuse leachates are tied directly to the pH of the system. Initially, at low pH, the leachates contain relatively high dissolved salt contents. As the pH begins to rise and level off, the leachate salt values begin a corresponding decrease and leveling. This relationship between the level of dissolved solids in the leachates and pH is analogous to that observed under static/equilibrium conditions.

The pH and TDS curves in Fig. 6 reflect the compositional differences in the three refuse types. Plant A, which contains the highest abundance of calcite, also exhibits by far the steepest rise in pH values (and corresponding drop in TDS content) as the experiment progresses. Cleaning Plants B and C contain relatively little calcite; therefore, the leachate increments from these two refuse types remain relatively acidic throughout the experiment. Interestingly, even the modest decreases in leachate acidity as a function of leachate volume displayed by the Plants B and C refuse result in rather substantial drops in TDS levels.

Trace element behavior during the continuous leaching of the Illinois Basin refuse samples generally parallels that of the TDS values (Appendix L). Initially, when leachate acidities are relatively high, the elemental concentrations also tend to be high, but as the leachate pH begins to increase with increasing effluent volume, the trace element concentrations in the leachates begin to decrease nearly exponentially. An example of this behavior for aluminum, iron, and cobalt is given in Fig. 7.

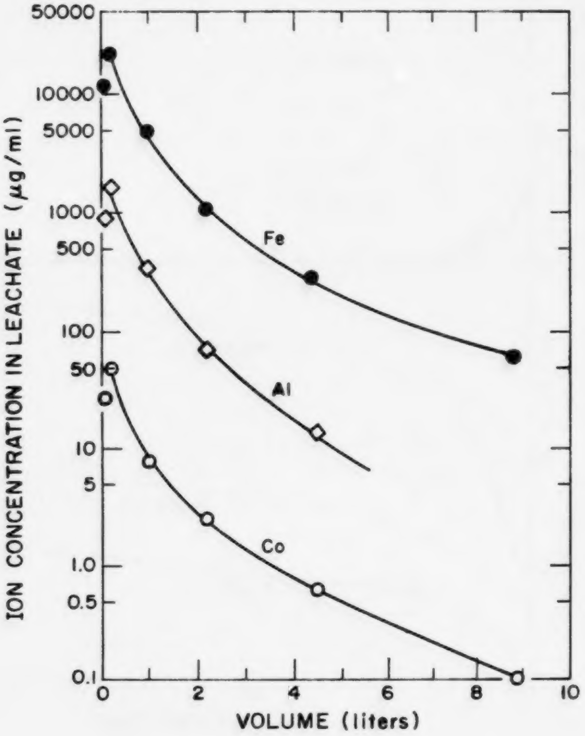

Fig. 7.
The concentrations of iron, aluminum, and cobalt as a function of leachate volume during the continuous leaching of refuse from cleaning Plant B.

The information on elemental releases collected from the continuous leaching studies shows rather conclusively that the greatest potential for trace element contamination of refuse dump effluents occurs during the earliest contact with the refuse material. This occurs very frequently in nature as rains or seasonal water flows intermittently permeate refuse disposal areas. We have chosen, therefore, the initial period of leaching in which to assess the nature and magnitude of the trace element releases from the Illinois Basin refuse during dynamic leaching. To assist in the endeavor, the ranges of concentration of the trace elements studied in the leachates after about 100 ml of leachate had been passed through the refuse column have been reported in Tables XXXI through XXXIII. The tables show that many of the same elements that were detected in high concentrations in the static leachates (for example, iron, magnesium, sodium, calcium, and aluminum) are also present in high concentrations in the leachates from the dynamic experiments. Among these are many potentially harmful trace elements present in concentrations exceeding 10 μg/ml of leachate, indicated by an asterisk in the table. Another point of interest brought out in these tables is that even for refuse from cleaning Plant A, which contains a substantial amount of an acid neutralizing agent (calcite), there is still a notable group of elements of environmental concern that are released into the flowing leachates. This, of course, reflects the fact that even the leachates from Plant A refuse are initially quite acidic under flowing leachate conditions (Fig. 6).

The elements just discussed are those leached from the refuse samples in relatively high concentrations. The amount of each released from the refuse, however, represents only a small part of the total of that element present in the refuse structure. Environmentally, we are also interested in identifying the trace elements in these refuse materials that are inherently highly leachable or soluble in flowing leachates. Because they will be easily released into the environment in a short period of time, these elements present an inordinately large potential to cause environmental harm even though they may not represent a large proportion of the total refuse structure.

TABLE XXXI

ELEMENTAL COMPOSITION OF LEACHATES FROM CONTINUOUS LEACHING EXPERIMENTS WITH PLANT A ILLINOIS BASIN COAL REFUSE

Experiment No. GL-19[a]

Leachate Concentration, μg/mℓ Leachate[b]	Element
> 500	Mg, Ca, Fe*
100-500	Al*
10-100	Na, K, Mn*, Co*, Ni*, Zn*
< 10	Sc, V, Cr, Cu, Ga, As, Br, Rb, Ag, Cd, Sb, Cs, La, Ce, Sm, Eu, Dy, Yb, Lu, Hf, Ta, W, Hg, Pb, Th, U

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[*] Of environmental concern (see Task III).

[a] Conditions: -3/8-in. refuse, 100 mℓ leachate, room temperature.

[b] pH = 2.9.

TABLE XXXII

ELEMENTAL COMPOSITION OF LEACHATES FROM CONTINUOUS LEACHING EXPERIMENTS WITH PLANT B ILLINOIS BASIN COAL REFUSE

Experiment No. GL-8[a]

Leachate Concentration µg/mℓ Leachate[b]	Element
> 500	Al*, Ca, Fe*
100-500	Mg
10-100	Na, Si, K, Mn*, Co*, Ni*, Zn*
< 10	Sc, V, Cr, Cu, Ga, As, Br, Rb, Ag, Cd, Sb, Cs, La, Ce, Sm, Eu, Dy, Yb, Hf, Ta, W, Hg, Pb, Th, U

---

[*] Of environmental concern (see Task III).

[a] Conditions: -3/8-in. refuse, 100 mℓ leachate, room temperature.

[b] pH = 1.7.

TABLE XXXIII

ELEMENTAL COMPOSITION OF LEACHATES FROM CONTINUOUS LEACHING EXPERIMENTS WITH PLANT C ILLINOIS BASIN COAL REFUSE

Experiment No. GL-20[a]

Leachate Concentration µg/mℓ Leachate[b]	Element
> 500	Na, Fe*, Ca
100-500	Mg
10-100	Al*, K, Mn*, Co*, Ni*, Zn*
< 10	Sc, V, Cr, Cu, Ga, As, Br, Rb, Ag, Cd, Sb, Cs, La, Ce, Sm, Eu, Dy, Yb, Lu, Hf, Ta, W, Hg, Pb, Th, U

---

[*] Of environmental concern (see Task III).

[a] Conditions: -3/8-in. refuse, 100 mℓ leachate, room temperature.

[b] pH = 2.4.

To provide a measure of the ease with which the trace elements studied are released from the refuse samples into the flowing leachates, we have coined a term called the "environmental activity factor" or EAF. The EAF is the dynamic equivalent of the elemental release percentages reported in Tables XX through XXII for the static leaching studies. The EAF for any element is defined by the equation

$$\text{EAF} = \frac{(\text{leachate concentration in } \mu\text{g/ml})_{v=0.1}}{(\text{refuse concentration in } \mu\text{g/g}} \times 100 \quad ,$$

where v = 0.1 specifies that the elemental concentration used in the calculation is that in the leachate after 100 ml (0.1ℓ) has passed through the refuse column. (It is understood that an EAF calculation can be made at any increment of leachate volume.) The calculated EAF values in actuality are modified "percentage released" calculations. Hence, the most highly leachable elements, when the calculation is made, are those exhibiting the highest EAFs. The EAFs for the elements studied in the 100-ml increments of the continuous leaching studies are presented in Tables XXXIV through XXXVI. The EAF values in the tables reveal that several elements, such as cobalt, nickel, cadmium, manganese, and zinc, while not leachable in high absolute quantities, are nonetheless rapidly leached from the refuse, and therefore, are classed as being quite environmentally active during the early stages of dynamic leaching. As we will discuss later in this report, these elements are of considerable environmental concern in the Illinois Basin refuse materials. Interestingly, most of the elements that were found to be highly releasable in the continuous flow studies are the same elements that were released in high percentages during the static leaching experiments.

A second type of dynamic leaching experiment conducted during the year was intermittent flow or discontinuous column leaching, designed to determine the degree to which the acid- and salt-forming potential of IIllinois Basin refuse is regenerated by halting the flow of leachate

TABLE XXXIV

ENVIRONMENTAL ACTIVITY FACTORS FROM CONTINUOUS LEACHING EXPERIMENTS
WITH PLANT A ILLINOIS BASIN COAL REFUSE

Experiment No. GL-19[a]

Leachate Environmental Activity Factor[b]	Element
> 25	Co*, Ni*, Cd*
10-25	Mg, Mn*, Zn*
1-10	Na, Ca, Sc, Fe, Cu, La, Ce, Sm, Eu, Dy, Yb, Lu, Th, U
< 1	Al, K, V, Cr, Ga, As, Cs, Hf, Pb

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*Of environmental concern (see Task III).

[a] Conditions: -3/8-in. refuse, 100 mℓ leachate, room temperature.

[b] pH = 2.9.

TABLE XXXV

ENVIRONMENTAL ACTIVITY FACTORS FROM CONTINUOUS LEACHING EXPERIMENTS WITH PLANT B ILLINOIS BASIN COAL REFUSE

Experiment No. GL-8[a]

Leachate Environmental Activity Factor[b]	Element
> 25	Ca, Sc, Mn*, Co*, Ni*, Zn*, Cd*
10-25	Mg, Fe*, Cu*, Eu, Dy, Yb, Lu Th, U
1-10	Na, Al, V, As, La, Ce, Sm
< 1	K, Cr, Pb

---

*Of environmental concern (see Task III).

[a] Conditions: -3/8-in. refuse, 100 mℓ leachate, room temperature.

[b] pH = 1.7.

TABLE XXXVI

ENVIRONMENTAL ACTIVITY FACTORS FROM CONTINUOUS LEACHING EXPERIMENTS WITH PLANT C ILLINOIS BASIN COAL REFUSE

Experiment No. GL-20[a]

Leachate Environmental Activity Factor[b]	Element
> 25	-
10-25	Na, Sc, Co*, Sm, Eu, Dy
1-10	Mg, Mn, Ni, Zn, As, Cd, La, Ce, Yb, Lu, Th, U
< 1	Al, K, Ca, V, Cr, Fe, Cu, Ga, Cs. Hf, Pb

---

*Of environmental concern (see Task III).

[a] Conditions: -3/8-in. refuse, 100 mℓ leachate, room temperature.

[b] pH = 2.4.

through the refuse bed and allowing the material to equilibrate in air. This condition is very prevalent in most refuse disposal areas where seasonal variations in precipitation or water flows cause erratic or only intermittent contact of the refuse dump with surface or ground water.

An example of the trends in leachate pH and salt content for an interrupted column leaching experiment using Plant B refuse is shown in Figs. 8 and 9. In this instance, leachate flow was interrupted at about 2.7ℓ and air was passed through the refuse column for 1 day. Then normal flow was commenced until a total of about 8.7ℓ of leachate had passed through the column and flow was again interrupted. After passing dry air through the column, this time for 7 days, leachate flow was again started and continued until the end of the experiment. The dashed vertical lines on the abscissas of the plots in Figs. 8 and 9 denote the places in the experiment where flow was stopped and the refuse was dried. After 1 day of refuse drying, there was slight evidence that pH had begun to again decrease and salt content to increase. A much larger effect in this direction was noted after 7 days of refuse drying. In this case about 5 to 10% of the original capacity of the refuse material to produce dissolved salts was regenerated; however, in another column leaching experiment, where we interrupted leachate flow and passed alternating dry and wet air through the refuse bed for a period of 3 weeks, we succeeded in regenerating about 35% of the original potential of the refuse material to contaminate aqueous leachates. These experiments convince us that under some circumstances in the field, the refuse material will return to a condition approximating its original chemical state and that subsequent leaching will again result in the release of large quantities of acid and dissolved salts.

This observation is extremely important because it implies that the capacity of refuse dumps to contaminate aqueous drainage with acids and trace elements is substantially regenerated each time there is an opportunity for the dump to thoroughly dry out. This means, strangely enough, that refuse banks or waste dumps that have only occasional intrusions of water may have far more potential for contaminating the surrounding environment than do those continually in contact with water.

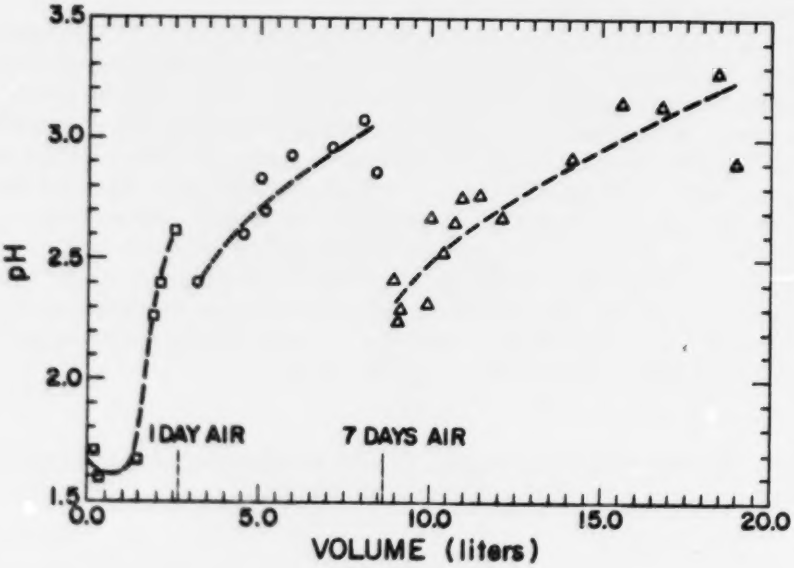

Fig. 8.
The effect of discontinuous flow on leachate pH values for a column leaching experiment.

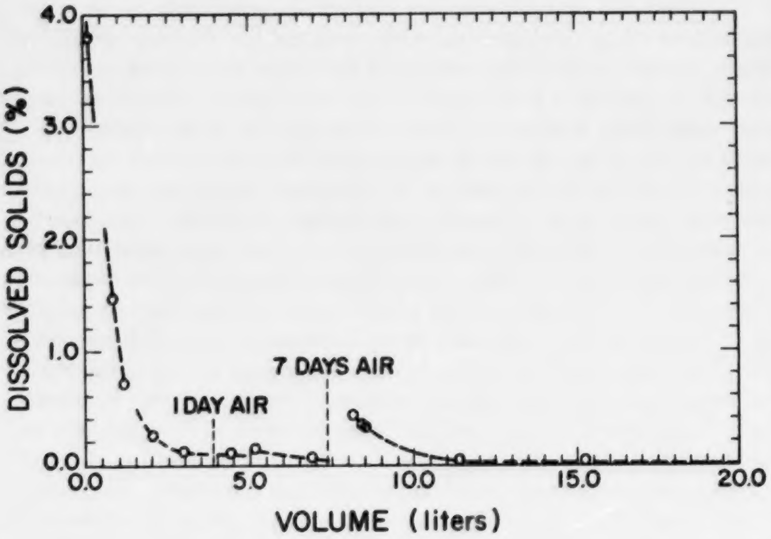

Fig. 9.
The behavior of leachate salt content when flow is interrupted in a column leaching experiment.

Subtask 2.2—Model the Environmental Behavior of Coal Wastes

During FY 77, we began to investigate the usefulness of thermodynamic models for predicting the weathering and leaching behavior of coal refuse systems. Unfortunately, we did not progress in this endeavor as well as originally planned.

For our initial work, we chose a complex equilibrium model developed by Ma and Shipman (Y. H. Ma and C. W. Shipman, AEChE Journal 18, 299-304, 1972), being used at LASL to model scale formation from geochemical brines. The original model, as developed by Ma and Shipman, however, applied only to mineral melts and solid solutions. Therefore, their routine was modified by LASL scientists to include a solvent, so the behavior of mineral mixtures in aqueous solution at equilibrium could be modeled. Unfortunately, this modification to the model was not completed during the year, and we were unable to apply the model to our purpose.

Our intent was to use the modified model to predict the solubilities of the major elements or minerals in Illinois Basin refuse during static/equilibrium leaching with water. This was to be done by checking the correspondence between the concentrations of the various species identified in the experimental leachates with those predicted by the model. We will make this comparison when the model is satisfactorily modified and debugged.

TASK 3—IDENTIFY TRACE ELEMENTS OF ENVIRONMENTAL CONCERN IN COAL PREPARATION WASTES AND RECOMMEND POLLUTION-CONTROL TECHNOLOGY

Two main research areas were addressed in this task. One involved compiling and evaluating the information and experimental results collected during the course of the program, and identifying the trace elements of environmental concern in coal preparation wastes from the Illinois

Basin. In the other we began studies to identify and recommend suitable technology to prevent or control the release of trace elements from the Illinois Basin refuse materials.

Subtask 3.1—Identify the Trace Elements of Environmental Concern in Coal Refuse

One of the main objectives of this program for FY 77 was to identify the trace elements in the drainage from Illinois Basin coal refuse that have the greatest potential for causing environmental damage. Much of the focus of our research both on refuse structure and environmental behavior was directed toward this end.

Two criteria were considered in arriving at a compilation of the environmentally troublesome elements. First, the element in question must be a known or suspected toxic substance, especially in aqueous systems. This is a difficult area to assess considering differences in plant and animal tolerances for the elements under consideration. For the moment, however, we have chosen elements that are reported to be generally toxic to plants and animals in concentrations comparable to those available in the coal refuse. (See for example: "Effects of Trace Contaminants From Coal Combustion," Proceedings of a Workshop, Sponsored by ERDA/DBER, August 2-6, 1976, Knoxville, Tennessee, ERDA 77-64; and "Trace Element Emissions: Aspects of Environmental Toxicology," Chap. 15 in *Trace Elements in Fuel*, S. P. Babu, Ed., Advances in Chem Series **141**, Am. Chem. Soc. 1975.) Also, to be included in our list of suspect elements, the element must be leached in relatively high quantities or be readily released from the refuse material under normal waste dump conditions. This condition means either that the element is present in the matrix of a labile or reactive refuse mineral, such as the pyrites, carbonates,or phosphates, or that it has been shown by experimental studies to reside in the refuse in a highly leachable state. Of the approximately 55 elements in the Illinois Basin refuse, only a few meet these criteria.

The trace elements listed in Table XXXVII are those in the refuse that we identified in Task 1, either by statistical studies or direct microprobe analyses, as being present in or highly associated

TABLE XXXVII

ELEMENTS HIGHLY ASSOCIATED WITH LABILE MINERALS IN

ILLINOIS BASIN COAL REFUSE[a]

Mineral	Major Constituents	Associated Elements
Pyrite/Marcasite	Fe,* S	
Carbonates	Ca, Mg, C	F,* Mn*
Phosphates	P, Ca	F

---

* Of environmental concern.

[a] Based on data from statistical correlations and microprobe analyses of selected samples of Illinois Basin refuse.

with labile or environmentally active mineral phases. The trace elements associated with the iron sulfide and carbonate constituents will be of concern because these minerals are often present in the waste in large quantities. Because the phosphate minerals are very minor components in the Illinois Basin materials, the trace elements associated with this mineral type exert a much less important influence on the ultimate composition of the waste effluents and are not considered. The elements that we consider to be potentially harmful in aquatic systems or soils, on the basis of mineralogy, are shown in Table XXXVII with an asterisk.

The leachabilities of the various refuse elements, as revealed by both static and dynamic laboratory leaching tests, were discussed in Task 2. In the static studies the trace element compositions of the leachates showed a general tendency to increase with time. The trace element contents of the dynamic leachates were initially observed to be quite high (on par with the elemental composition of the static leachates), but with continued leaching the contaminant levels of the dynamic leachates began to fall off in an exponential manner. We did find, however, that there was a marked tendency for the contaminant levels of the dynamic leachates to remain relatively high if the refuse samples were subjected to intermittently rather than continuously flowing leachates. We concluded that the leachabilities of the various refuse elements during the early stages of either static or dynamic leaching were a reasonable representation of the natural potential of refuse disposal areas to release toxic inorganic contaminants into associated waterways.

To identify the most environmentally troublesome trace elements in these refuse samples, we considered only those elements present in the initial dynamic leachates in amounts exceeding 10 μg/ml of leachate (10 μg leached/g of refuse for the static leachates) or that had leachability percentages or EAFs of 10 or greater. The elements meeting both the toxicity and leachability criteria were designated with an asterisk in the tables of leachate data reported in Task 2. A tabulation of these elements is presented in Table XXXVIII.

TABLE XXXVIII

TRACE ELEMENTS OF ENVIRONMENTAL CONCERN AS DELINEATED BY STATIC AND DYNAMIC LEACHING STUDIES OF ILLINOIS BASIN COAL REFUSE

Element	High Leachate Concentration[a]	High Leachability[b]
Al	x	
Mn	x	x
Fe	x	x
Co	x	x
Ni	x	x
Cu	x	x
Zn	x	x
Cd		x

---

a Elements present in initial dynamic leachates in excess of 10 μg/ml of leachate or in static leachates greater than 10 μg/g of refuse.

b Elements having EAF's or percent leachabilities of 10 or more in initial dynamic or static leachates.

A complete listing of the trace elements of greatest environmental concern in Illinois Basin refuse as delineated both by our mineralogical and leaching studies, appears in Table XXXIX. The elements listed will receive our greatest attention in subsequent studies of environmental control technology for refuse dump drainages and effluents.

Several points concerning our choices of the environmentally troublesome trace elements in the refuse samples deserve further comment. One concerns the required level of toxic element concentration in the leachates before consideration of an element as an environmental concern (10 μg/ml of leachate or 10 μg/g of refuse, depending on the type of experiment). Many toxic elements are, of course, harmful in aqueous systems in quantities much less than these; however, to avoid grossly overstating their real contamination potential, we purposely set our elemental composition limits at relatively high values. We hope, by this procedure, to have identified those elements most likely to cause environmental problems in refuse drainage (but certainly not every harmful element) without putting undue emphasis on the toxicology of specific elements.

An important point to bear in mind is that designating any level of trace element content in the refuse leachates as "safe" is rather arbitrary from an environmental viewpoint, because the actual harm that toxic elements in refuse drainage systems can cause is a function of how efficiently these elements are accumulated into sensitive areas of the surrounding ecosystem. This depends on a number of factors not directly connected with the refuse dump, including the total volume of contaminated drainage released from the disposal site, the degree that the contaminated drainage is diluted and carried away by adjacent waterways, and the ability of soils, plants, or animals in the area to concentrate specific toxic elements. The research reported here does not purport to answer these questions, but rather to call attention to those trace elements in the drainage from Illinois Basin refuse materials that have the greatest potential for causing environmental damage, and hence, should be given foremost consideration in the planning of effective environmental control strategies.

Finally, a question may be raised concerning the correspondence between our laboratory data on trace element releases from various refuse samples and the levels of trace element contamination in actual refuse dump drainage. Although we have attempted to incorporate generality into this study by stressing the relationship between refuse composition and environmental behavior, it is true that only a limited number of refuse samples or leaching conditions were used in our work. The validity of our data and conclusions is substantiated, however, by the good correspondence between the levels of elemental contaminants observed in our experimental leachates and a limited group of trace elements identified in actual refuse dump drainage from

TABLE XXXIX

TRACE ELEMENTS OF ENVIRONMENTAL CONCERN IN ILLINOIS BASIN COAL REFUSE

Element	Labile Mineral	Static Leaching	Dynamic Leaching
F	x		
Al		x	x
Mn	x	x	x
Fe	x	x	x
Co		x	x
Ni		x	x
Cu			x
Zn		x	x
Cd		x	x

widely diverse points in the Illinois Basin (Table XL). The high level of agreement between our results and the available information gathered from analyses of refuse dump drainages indicates convincingly that the leachates produced in the laboratory do indeed simulate the effluents from many refuse dumps throughout the Illinois Basin, and reflect the general types and levels of elemental contaminants that will need to be accommodated by any environmental control technology.

Subtask 3.2—Recommended Methods and Technology for Controlling Trace Element Contamination

One of the main reasons for studying the releases of trace elements from coal refuse materials during weathering and leaching is to provide useful information about the nature and seriousness of this form of contamination for planning and developing environmental control strategies for coal refuse dumps and disposal areas. Accordingly, the emphasis of our work over the past 2 years has been directed not only at identifying the trace elements in waste or refuse drainage that are most likely to cause environmental problems, but also at understanding the chemistry and behavior of these materials. Several of the principal conclusions from our studies of Illinois Basin coal preparation wastes carry implications concerning possible control technology methods and warrant further elaboration and discussion. One concerns the importance of pH in determining the levels of trace element contamination of refuse drainage. Throughout our studies, under all

TABLE XL

TRACE ELEMENT CONCENTRATION RANGES FOR EXPERIMENTAL LEACHATES AND FIELD SAMPLES OF DRAINAGE PRODUCED BY ILLINOIS BASIN COAL REFUSE

Element	Experimental Leachates, μg/ml[a]	Refuse Dump Drainage, μg/ml[b]
Na	21 - 700	18 - 270
Mg	61 - 369	90 - 285
Al	8.7 - 910	50 - 440
K	21 - 28	0.7 - 13
Ca	130 - 532	160 350
Mn	5.6 44	24 - 120
Fe	610 -12000	50 -13500
Co	3.7 - 28	
Ni	5.6 - 43	0.4 - 3.0
Cu	0.3 - 8	
Zn	2.2 - 55	1.7 - 8.0
Cd	0.02- 0.24	
pH	1.7 - 2.9	2.2 - 3.6

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[a] Data from LASL studies of the initial leachates from dynamic leaching of selected samples of Illinois Basin coal refuse.

[b] Data from analyses of samples of refuse pile drainage collected from various locations in the Illinois Basin as reported by Martin, Papers from "First Symposium on Mine and Preparation Plant Disposal," pp 26-37, 1974.

conditions of static and dynamic leaching, an inverse relationship prevailed between pH and the amounts of elements leached from the refuse samples. Thus, at low pH (high acidity) worrisome quantities of toxic elements were leached from all the refuse samples studied; whereas, in those systems where leachate acidity remained relatively low (pH 5 to 7), trace element leachability and the capacity of the leachates to solubilize contaminants were minimized. These observations suggest that preventing the initial formation of acids in refuse dumps, or neutralizing the acid drainage as it is formed, would be an effective means of controlling trace element releases into the environment.

Some of the many possibilities for alleviating or controlling acid formation in refuse leachates that we will investigate in future work include removal or fixation of acid-forming substances (iron sulfides) before refuse disposal, burying or sealing refuse piles to limit the influx of air and water, adding neutralizing agents to existing refuse materials, and neutralizing refuse drainage as it emerges from the disposal site.

Another observation which has implications in the control technology area comes from our studies of refuse trace element mineralogy. Here we observed that most of the elements identified as being of environmental concern reside as constituents of, or are embedded in, the refuse clay fractions. Even such chalcophile elements as cobalt, nickel, copper, zinc, and cadmium, which might have been expected to be associated with the major sulfide minerals, were found to be highly concentrated in the predominately clay areas of the refuse samples. The clay minerals represent a substantial part of the total refuse structure (usually more than 30%), but more important, the clay constituents are finely divided and intermixed with the other refuse fractions. Therefore, attempting to remove the clay refuse component, which contains the bulk of the trace elements that we are concerned with, before disposal (as has been suggested by some), appears to be highly impractical.

A related observation from our work concerns the ease with which many of the worrisome elements can be removed from the refuse materials simply by leaching them with aqueous acids. Our environmental studies with Illinois Basin refuse revealed that substantial percentages of the total manganese, iron, cobalt, nickel, zinc,and cadmium in the refuse materials can be removed by short-term leaching with dilute sulfuric acid. This suggests that many of the environmentally harmful elements in high-sulfur refuse could be removed before disposal by treating the crushed refuse with a dilute acid, and isolating the easily removable elements in the ensuing leachates. This process looks even more attractive when it is considered that the necessary acid could be generated in situ by the proper application of water and air to the refuse pyritic constituents. This process also will be given careful consideration in our future research.

A last observation from our studies is quite important when considering regional control of water pollution from coal refuse dumps. Some refuse materials pose a far greater pollution threat when they are only intermittently in contact with water than when they are continuously being leached. Therefore, we conclude that the highest priority and greatest emphasis in pollution abatement programs for coal refuse dumps should be given to those disposal sites that are frequently, but not continuously, in contact with surface or ground water.

We have also begun experiments to evaluate the potential of a number of techniques to control the acidity and trace element composition of coal refuse drainages. Our initial emphasis in this study is on techniques such as alkaline neutralization, ion exchange, reverse osmosis, and flash distillation. Each of these is used in the field, or under consideration, to control acid in the drainage from coal mines or refuse dumps. (A discussion of AMD control methods was presented earlier in our literature review of trace elements in coal cleaning wastes, published as EPA report 600/7-76-007, August 1976.) Results from our work with the various environmental control methods will be reported in the coming year.

TASK 4—ASSESS THE POTENTIAL FOR ENVIRONMENTAL CONTAMINATION FROM TRACE ELEMENTS AND ORGANIC COMPOUNDS IN THE EFFLUENTS FROM STORED COALS

The research described in this section was designed to determine the potential for environmental contamination from the trace elements and organic compounds that are released during the weathering and leaching of stored coals. The emphasis during FY 77 focused on how the various environmental conditions encountered during outdoor storage affect the character of the aqueous discharges from a high-sulfur Illinois Basin coal.

Subtask 4.1—Determine the Identities and Amounts of Inorganic and Major Organic Components Released by the Aqueous Leaching of Unwashed Coals Under Simulated Storage Conditions

The coal used in this study was an unwashed variety that we collected at the input feed of a coal preparation plant located in the Illinois Basin (cleaning plant E). This high-sulfur coal is one of the major varieties mined in the basin. The elemental composition of the coal is reported in Appendix B. A tabulation of the averages and extremes in elemental components for the two increments of the coal that were collected appears in Table XLI. The bulk mineralogical composition of this coal was not determined.

Analogous to the coal refuse studies, we completed a number of coal leaching experiments during the year using both the static equilibrium (Appendix H) and the dynamic (Appendix I) leaching methods. As in the case of the refuse investigation reported earlier in Task 2, we used the static experiments to determine the effects of pertinent experimental variables on the elemental composition of the leachates; the dynamic tests provided information on trace element releases from the coal under conditions more closely simulating those encountered during the outdoor storage of coal.

The static leaching studies of this high-sulfur Illinois Basin coal were completed about midyear. Two coal particle sizes, −3/8 in. and −20 mesh, were included in this study. These were chosen to determine the influence that coal surface area has on the leaching process. Both wet (as received) and predried coal samples were incorporated into the study to simulate the effects of preparation plant drying and long dry spells during coal storage. Distilled water was the leachate used in all instances. The experiments were conducted either at ambient temperature (22°C) or at 70°C. The high-temperature studies represent the interior conditions of coal piles maintained at hyperambient temperature by various heat-producing reactions (mainly the oxidation of coal and pyritic materials). Provisions were also made to study coal leaching behavior under conditions of low oxygen content in sealed vessels and when free access to air is maintained with an open reaction vessel. Low oxygen conditions often prevail at the interior of compacted coal heaps, but in poorly compacted piles there is often very good circulation of air. Finally, the experiments were conducted for a period of 28 days. Samples were removed from the shaker for analyses after leaching times of 10 min, and 1, 7, 14, and 28 days. These experiments simulate a variety of leaching conditions, from very mild to those which may prevail in the extreme where the stored coal is nearly continuously in contact with water. A listing of the various combinations of experimental variables under consideration in this study is given in Table XLII.

The effects of the various experimental parameters on the coal-leachate systems are reflected by the solution pH values, which were monitored throughout the experiment. The pH values at

TABLE XLI

TRACE ELEMENT COMPOSITION OF RAW COAL FROM ILLINOIS BASIN COAL PREPARATION PLANT E[a]

Element[b]	Low	High	Mean
Li	63	65	64
Be	20	22	21
B	62	70	66
F	60	80	70
Na(%)	0.03	0.03	0.03
Mg(%)	0.05	0.06	0.06
Al(%)	1.8	1.8	1.8
Si(%)	1.4	2.5	2.0
P	260	310	285
Cl	77	123	100
K(%)	0.23	0.26	0.24
Ca(%)	0.15	0.21	0.18
Sc	4.5	4.8	4.7
Ti(%)	0.08	0.10	0.09
V	37	50	43
Cr	21	30	26
Mn	42	58	50
Fe(%)	3.90	4.70	4.30
Co	13	13	13
Ni	26	42	34
Cu	33	38	36
Zn	22	32	27
Ga			6
Ge			< 8
As	24	43	34
Br	16	41	29
Y	29	37	33
Zr	39	55	47
Mo	16	25	21
Cd	0.15	0.21	0.18
Sn			< 8
Sb	0.79	1.38	1.08
Cs			2.4
La	19	22	21
Ce	31	34	32
Sm	2.3	2.5	2.4
Eu	0.7	0.9	0.8
Dy	3.1	3.8	3.5
Yb	1.1	3.1	2.1
Lu	0.2	0.2	0.2
Hf	0.4	1.3	0.8
Pb	11	11	11
Th	3.4	3.5	3.5
U	2.5	2.6	2.6

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[a] Analyses included coal samples 36 and 37.

[b] Elemental compositions reported as μg/g coal unless otherwise noted.

TABLE XLII

EXPERIMENTAL CONDITIONS USED IN STATIC/EQUILIBRIUM LEACHING STUDY OF ILLINOIS BASIN COAL

Time		10 min.		1 Day			7 Days			14 Days		28 Days		
Atmosphere [(a)]		S		S	O	O	S	O	O	S		S	O	O
Temperature, °C		22		22	22	75	22	22	75	22		22	22	75
COAL SAMPLE	-20 mesh, dry	X[(b)]					X					X		
	-20 mesh, wet	X		X	X	X	X	X	X	X		X	X	X
	-3/8 in.	X		X	X	X	X	X	X	X		X	X	X

(a) S = sealed vessel, O = open vessel.

(b) The combinations of variables studied are designated by an X.

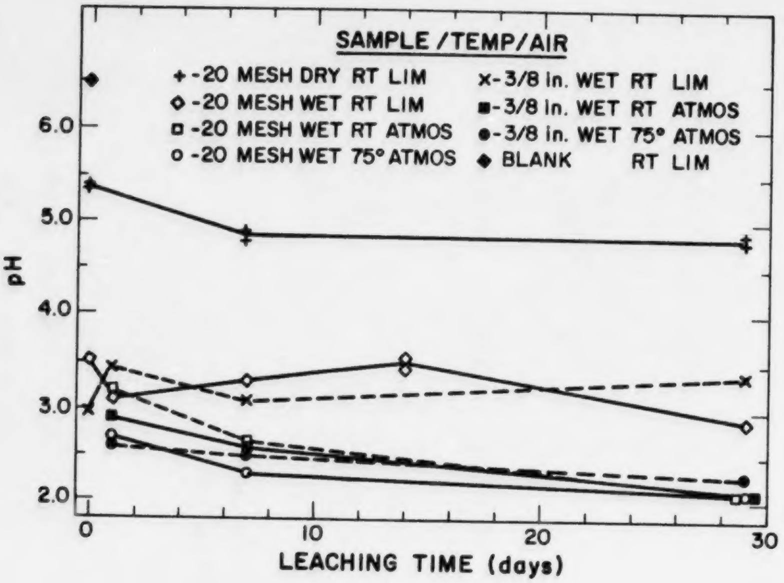

Fig. 10.
Leachate pH as a function of experimental variables for leaching study of Illinois Basin coal.

the termination of the leaching experiments are illustrated in Fig. 10. Several striking observations can be made about these data. First, the pH of all of the leachate solutions dropped very rapidly upon initial contact with the crushed coal. In fact, given some slight variation with time, most of the change in solution pH occurred within the first 10 min of contact with the coal. Therefore, there is a very short time dependence connected with the build-up of free hydrogen ion in the aqueous leachate. Another interesting point is that the temperature of the leaching experiment had little effect on the pH of the solution. The pH values were similar for both the ambient and high-temperature conditions. Also, the solution pH was little affected by the particle size (surface area) of the coal. The two variables having the greatest effect on leachate pH were whether the coal was dry or wet when it came into initial contact with the water, and whether there was free or restricted air flow into the leaching zone. In each instance, the pH of the leachates associated with the predried coal was substantially higher than those in contact with the wet coals. Likewise, the pH of the leachate solutions are significantly higher for those coal/leachate mixtures in which the flow of air into the system was severely restricted.

The trace element levels and other pertinent data for the various leachates from the static leaching studies of the Illinois Basin coal are reported in Appendix M. To clarify the effects of the experimental variables, we have retabulated the data for several of the more highly leachable elements and presented them as Tables XLIII through IL. For comparison, the leachate trace element concentrations are expressed in μg of element released per g of coal leached. Thus, in considering the leaching experiments, the values reported represent the total mass of a particular element released per g of coal, regardless of solution volume.

The major observation to be made from the information in Tables XLIII through IL is that the leachabilities of the 12 elements listed generally increased with time although the data for several elements are somewhat erratic. In all cases iron was by far the element most abundantly leached from the coal samples, indicating that much dissolution of pyritic material occurred during the leaching treatment. Also, in nearly all instances, calcium (not shown), aluminum, and

TABLE XLIII

STATIC/EQUILIBRIUM LEACHING OF ILLINOIS BASIN COAL

CONDITIONS: WET COAL, - 3/8 IN., 22^{0}C, LIMITED AIR

Elements Leached (µg/g of coal)

Leaching Time (days)	Fe	Al	Na	K	Mg	Cr	Mn	Co	Ni	Cu	Zn	Cd
10 min	1820	25	12	1.0	30	0.12	8	5	10	1.4	5.0	0.06
1	1060	12	23	3.8	30	0.09	10	7	12	0.50	4.9	0.07
7	2220	28	42	2.9	45	0.14	14	8	14	0.75	9.1	0.05
14												
28	3420	35	62	21.8	50	0.20	14	5	14	<0.10	5.4	0.05

TABLE XLIV

STATIC/EQUILIBRIUM LEACHING OF ILLINOIS BASIN COAL

CONDITIONS: WET COAL, - 20 MESH, 22^{0}C, LIMITED AIR

Elements Leached (µg/g of coal)

Leaching Time (days)	Fe	Al	Na	K	Mg	Cr	Mn	Co	Ni	Cu	Zn	Cd
10 min	1270	56	24	1.4	50	0.10	13	7.0	16	0.63	7.2	0.05
1	1090	50	20	0.6	55	0.09	16	8.0	19	0.42	9.1	0.06
7	2590	62	14	0.4	55	0.13	18	11	22	<0.10	11.6	0.07
14	2755	54	14	1.6	55	0.14	17	10	19	<0.10	11.9	0.07
28	3150	94	9	12.5	55	0.20	18	10	19	0.20	14.1	0.08

TABLE XLV

STATIC/EQUILIBRIUM LEACHING OF ILLINOIS BASIN COAL
CONDITIONS: WET COAL, -3/8 IN., 22°C, UNLIMITED AIR

Leaching Time (days)	Elements Leached (μg/g of coal)											
	Fe	Al	Na	K	Mg	Cr	Mn	Co	Ni	Cu	Zn	Cd
1	1880	29	54	8.8	45	0.150	10.0	7.0	12.0	0.150	6.56	0.05
7												
14	1950	25	32	1.2	30	0.140	10.0	7.0	14.0	0.140	4.12	0.04
28	10060	75	46	1.1	50	0.270	25.0	8.0	18.0	0.270	7.19	0.05

TABLE XLVI

STATIC/EQUILIBRIUM LEACHING OF ILLINOIS BASIN COAL
CONDITIONS: WET COAL, -20 MESH, 22°C, UNLIMITED AIR

Leaching Time (days)	Elements Leached (μg/g of coal)											
	Fe	Al	Na	K	Mg	Cr	Mn	Co	Ni	Cu	Zn	Cd
1	1100	52	20	1.5	50	0.100	17.0	9.0	17.0	0.100	9.06	0.07
7	3260	75	4	1.0	45	0.150	17.0	9.0	17.0	0.150	10.9	0.07
14												
28	16440	155	2	0.8	50	0.230	25.0	12.0	27.0	0.230	21.6	0.11

TABLE XLVII

STATIC/EQUILIBRIUM LEACHING OF ILLINOIS BASIN COAL

CONDITIONS: WET COAL, -3/8 IN., 75°C, LIMITED AIR

Elements Leached (μg/g of coal)

Leaching Time (days)	Fe	Al	Na	K	Mg	Cr	Mn	Co	Ni	Cu	Zn	Cd
1	2480	28	33	5.2	45	0.15	12	7	13	0.31	7.19	0.054
7	3170	50	37	10.6	55	0.19	13	7	13	0.70	6.56	0.054
14												
28	5550	160	70	28.7	80	0.26	17	26	15	0.63	8.44	0.07

TABLE XLVIII

STATIC/EQUILIBRIUM LEACHING OF ILLINOIS BASIN COAL

CONDITIONS: WET COAL, - 20 MESH, 75°C, LIMITED AIR

Elements Leached (μg/g of coal)

Leaching Time (days)	Fe	Al	Na	K	Mg	Cr	Mn	Co	Ni	Cu	Zn	Cd
1	4100	47	27	7.7	55	0.18	20	10	21	0.38	12.2	0.07
7	7500	120	62	36	80	0.23	24	12	24	0.30	19.1	0.09
14												
28	10750	410	89	54	95	0.40	22	10	22	1.88	24.7	0.10

TABLE IL

STATIC/EQUILIBRIUM LEACHING OF ILLINOIS BASIN COAL

CONDITIONS: DRIED COAL, - 20 MESH, 22°C, LIMITED AIR

Elements Leached (μg/g of coal)

Leaching Time (days)	Fe	Al	Na	K	Mg	Cr	Mn	Co	Ni	Cu	Zn	Cd
10 min	23	<1	66	20.0	30.0	0.032	5.0	5.0	10.0	<0.01	0.82	0.02
1												
7	73	<1	73	26.7	40.0	0.057	10.0	7.0	12.5	<0.01	1.62	0.02
14												
28	300	<1	79	28.3	42.5	0.065	11.0	7.0	14.0	<0.01	2.72	0.03

magnesium were leached in relatively high quantities from the coals. This undoubtedly resulted from the dissolution of the clay and carbonate minerals. Sodium and potassium were often observed in the leachates in amounts comparable to aluminum and magnesium, but the behavior of these elements was somewhat erratic perhaps because they tend to form ion-exchange complexes with both the clay and carbon fractions of the coal. Other elements that were consistently leached from the Illinois Basin coal in appreciable quantities (>10 μg/g of coal) include manganese, nickel, zinc, and cobalt.

A few elements, for example iron, aluminum, and chromium, appeared in all instances to be continuously released from the coals as a function of leaching time, and showed little sign of approaching an equilibrium condition. Others, like magnesium, were leached to the maximum relatively quickly. In some cases, some elements (sodium, potassium, and copper) appeared to decrease in concentration from the leachate as time went on. This phenomenon probably resulted from the time-dependent adsorption or recombination of the elements with the coal residues or other parts of the experimental system.

The effects of coal particle size (surface area), system temperature, and oxygen content on the leachabilities of the observed elements are somewhat variable depending on the element. Generally, higher elemental concentrations in the leachates were obtained from the smaller coal particles (compare Tables XLIII and XLIV, XLV and XLVI, XLVII and XLVIII). This illustrates a positive enhancement of mineral solubility by increasing coal surface area. Increasing the system temperature similarly enhanced the solubility of the various elements in the leachates (Tables XLIII and XLVII, XLIV and XLVIII). And, other things being equal, the coal-leachate systems that had unlimited access to air exhibited the greatest degrees of elemental dissolution (Tables XLIII and XLV, XLIV and XLVI). The most dramatic effect of all was caused by drying the coal sample before it was leached (see Tables XLIV and IL). The amounts of iron and aluminum leached from the predried coal were substantially lower than the amounts leached from the as-received material, and most other elements were correspondingly lower. We observed much the same effect from predried coal with regard to leachate pH. We do not have an explanation for this.

In addition to the static leaching studies, we conducted several leaching experiments with the Illinois Basin coal using the dynamic column method. These experiments, like those with the Illinois Basin refuse samples, were conducted according to the procedure outlined in Appendix I. In contrast to the static leaching experiments, where a constant and single volume of water is used, these dynamic experiments feature a flowing leachate that is constantly pumped through a column of crushed coal. The values for leachate pH and TDS, and the trace element compositions of the various dynamic coal leachates are reported in Appendix N.

The trends in leachate pH and TDS for the continuous column leaching studies of crushed Illinois Basin coal (CL 7 and 8) are given in Figs. 11 and 12. Initially, the acid generating capacity of the coal system is quite high, but with increasing leachate volume, pH begins to rise and level off. The behavior of dissolved solids in the leachate corresponds roughly with the acidity of the leachate. Initially, at low pH, the leachate contains a relatively high salt content (approaching 4 wt%). As the pH curve begins to rise and flatten with greater leachate volume, the TDS content drops dramatically and eventually levels off at a relatively low constant value.

The data in Appendix N show that the trace element release patterns for the coal samples during continuous leaching are similar to those exhibited by the Illinois Basin refuse samples. Initially, at high acidity, elemental concentrations in the dynamic leachates are also high. However, as acidity drops with continued leaching, trace element concentrations for most elements also decrease (similar to the TDS behavior shown in Fig. 12) to values 1% or less of the initial concentrations.

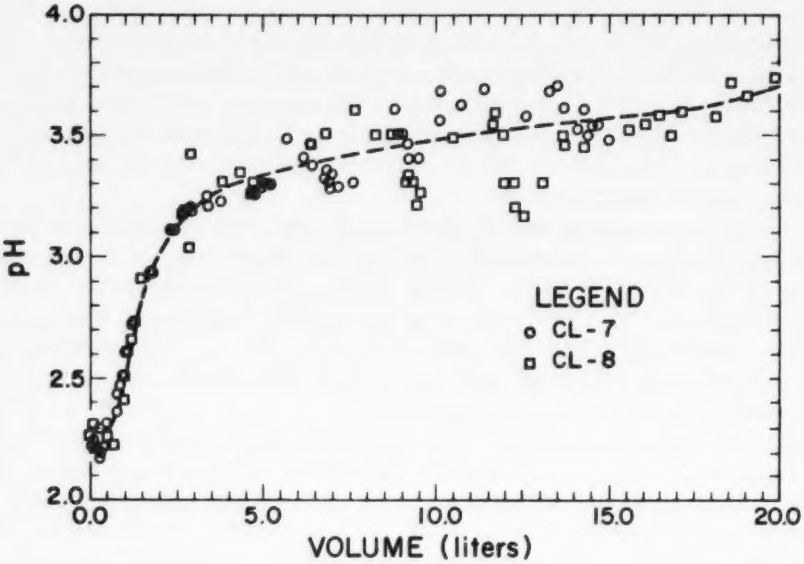

Fig. 11.
Leachate pH from a continuous leaching experiment with Illinois Basin coal.

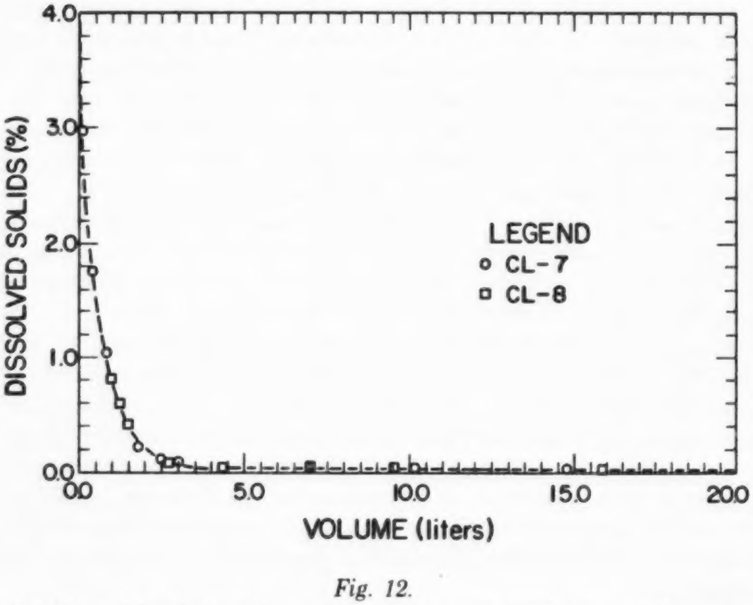

Fig. 12.
TDS as a function of leachate volume for a continuous leaching experiment with Illinois Basin coal.

To simulate rainy and dry weather cycles, we conducted dynamic leaching studies with the Illinois Basin coal samples in which we incorporated intermittent flow conditions. In these experiments (results reported in Appendix N) leachate flow was interrupted at several points, air was passed through the packed coal column for periods of up to 7 days, and flow was again started. The effects of intermittently leaching the coal sample are shown in Figs. 13 and 14 for experiment CL-5. As we observed earlier for coal refuse systems, these coals also have a substantial capacity for contaminant regeneration when leachate flow is interrupted and the coal is allowed to dry. As Figs. 13 and 14 show, particularly vividly after the 7-day column drying period, both the leachate acidity and solids content tend to rise significantly following a pause in leachate flow. This is strong evidence that, analogous to the refuse materials studied, Illinois Basin Coals will remain a high potential source of mineral and trace element contamination regardless of the age of the coal or storage pile.

Our studies of the Illinois Basin coal leachates also involved assessing their organic compositions. Our objective here was to determine the degree to which drainage from coal storage piles might be contaminated with organic compounds, and, if possible, to identify these compounds.

Total organic carbon contents (TOC) were determined for several of the leachates from the static/equilibrium study of the Illinois Basin coal sample. The TOC values for these leachates ranged from about 5 to 50 ppm. These values are only rough approximations because our analytical reproducibility was poor, but they do represent typical levels of organic carbon to be found in the coal leachates.

After determining how much organic material was in the coal leachates, we wanted to identify the natures of their individual species. It was necessary first to separate these components into groups or classes and then to subdivide them further into smaller groups or individual species suitable for identification by mass spectrometry, infrared spectroscopy, or nuclear-magnetic-resonance spectroscopy. Most of our remaining effort in this area was spent on achieving these separations with chromatographic techniques.

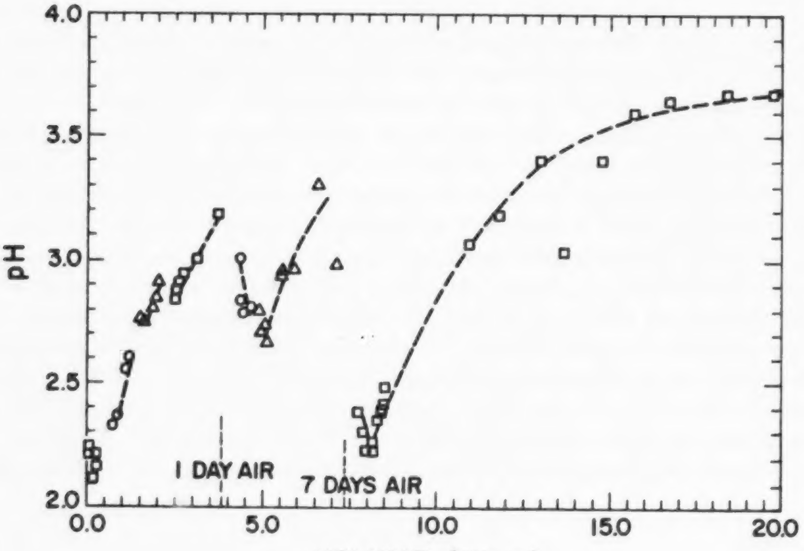

Fig. 13.
The effect of interrupted flow on leachate pH for Illinois Basin coal.

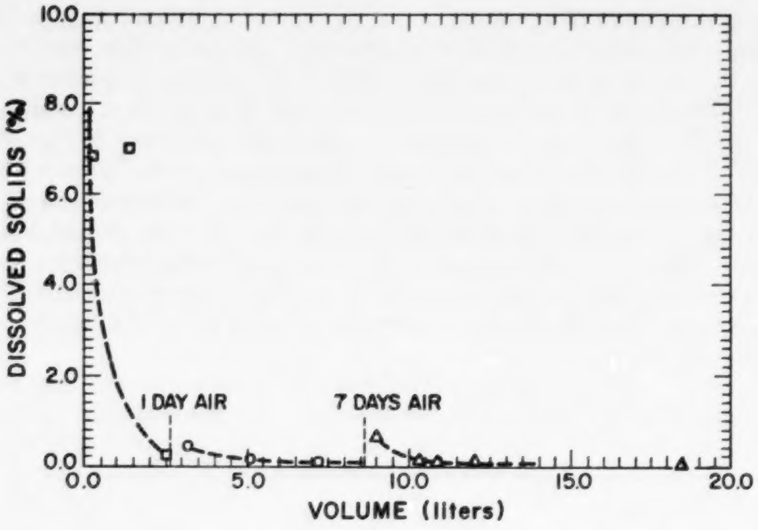

Fig. 14.
The effect of discontinuous flow on leachate solids content for Illinois Basin coal.

Isolation and partial separation of the organic contaminants in samples of the coal leachates was accomplished with a chromatographic method called reverse-phase, gradient-elution, liquid chromatography. This technique has been widely used to effect separation of organic contaminants from drinking water. With this method, the contaminants are removed from the aqueous solutions by passing the solutions through a nonpolar chromatography column which retains the organic molecules. Usually a relatively large volume of contaminated water or leachate is passed through the column (in our work, up to 50 ml) to concentrate the organic impurities in sufficient quantities for analysis. The organic matter held on the column is then progressively removed by eluting with mixtures of organic solvents. The separated components or fractions are collected as they emerge from the chromatography column and prepared for analyses.

A typical liquid chromatogram of the organic constituents removed from a coal leachate (as described above) is given as Fig. 15. The first very broad peak appearing after the injection point is composed mainly of compounds containing inorganic elements. Whether these are present in the form of organometallic complexes or in ionic form is not yet known. The group of smaller peaks in the middle part of the chromatogram (elution volumes in the range 20 ml to 35 ml) are polar organic molecules; i.e., oxygen-, nitrogen-, or sulfur-containing compounds. Finally, the last peaks to elute (at >35 ml of solvent) are the nonpolar organic constituents.

We have completed a small number of mass spectral analyses of several of the organic fractions obtained from the chromatographic separations. Our results are far from conclusive, but they indicate that most of the organic components in the coal leachates are heteroatom (nitrogen, sulfur, oxygen) containing aliphatic or alicyclic compounds. No direct evidence of phenol or other aromatic compounds, however, was obtained from this superficial mass analysis.

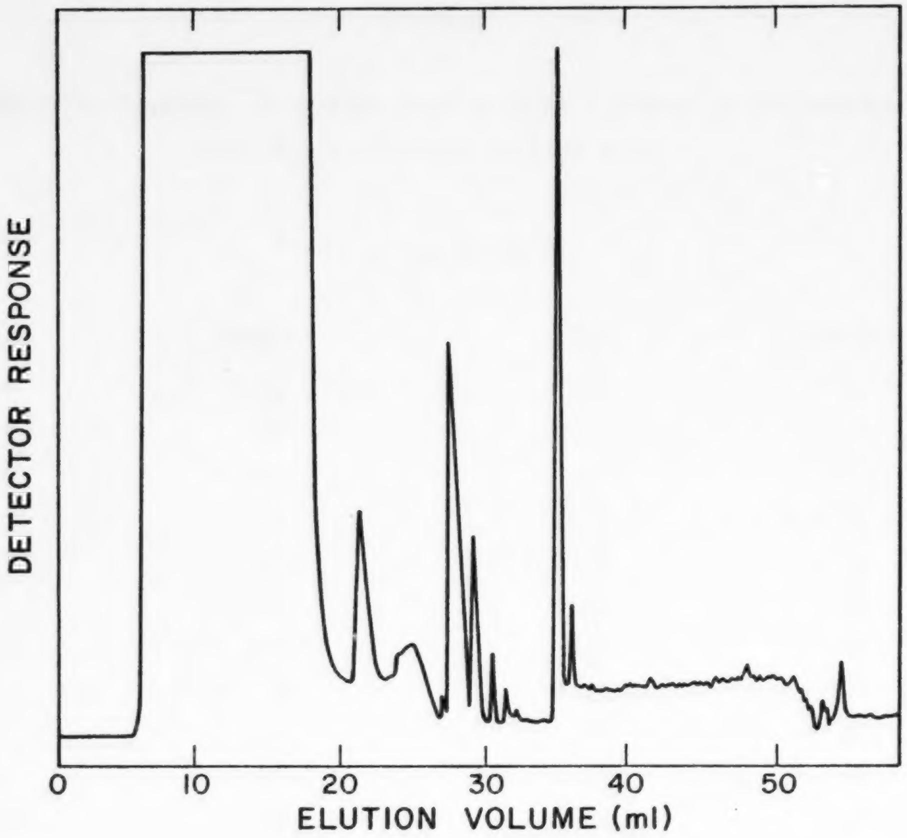

Fig. 15.
Liquid chromatogram of organic contaminants in coal leachate obtained by passing 10 ml of leachate through a 4-mm-i.d. by 30-cm Bondapak C-18 column followed by elution with a linear gradient progressing from pure water to pure acetonitrile at a flow rate of 2.0 ml/min.

Subtask 4.2—Obtain Data on the Relative Release Rates of Specific Inorganic and Organic Components From Stored Cells

The purpose of this subtask was to compute or calculate the relative release rates of the various trace elements and organic contaminants during aqueous leaching of an Illinois Basin coal sample. This effort was satisfactorily completed for the inorganic leachate contaminants, but the limited study that we completed on the organic components of the leachates did not provide sufficient information to make a similar assessment.

Our work on relative release rates of the trace elements in the coal sample concentrated on the dynamic leaching studies, which are more representative of actual storage pile conditions. Initially we plotted leachate elemental concentrations as a function of time and then determined rate expressions for each element. After inspecting the complex polynomial equations necessary to describe the trace element leaching data, we concluded that more understandable release data would result simply by comparing the EAFs (defined in Task 2) for each element in the initial leachates. A tabulation of the EAFs for the elements studied in the 200-ml increment of one of

TABLE L

ENVIRONMENTAL ACTIVITY FACTORS FROM CONTINUOUS LEACHING EXPERIMENT WITH PLANT E ILLINOIS BASIN COAL

Experiment No. CL-7[a]

Element	EAF[b]	Element	EAF[b]
Co*	74.6	Na	9.7
Ni*	52.9	Yb	9.5
Zn*	48.2	Sc	8.9
Cd*	46.1	U	7.2
Mn*	45.9	Lu	5.0
Ca	20.0	La	2.6
Dy	18.3	Ce	1.8
Cu	16.9	V	1.3
Mg	15.5	Al	0.7
Fe	13.5	Cr	0.6
Sm	11.7	Pb	0.4
Eu	11.3	K	0.2
Th	11.2		

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* Of environmental concern.

a Conditions: -3/8-in. coal, 200 ml leachate, room temperature.

b pH = 2.2.

the dynamic leaching experiments (CL-7) appears in Table L. The EAFs cluster into groups reflecting relative leachabilities or release rates. Cobalt, as we also observed from the studies of Illinois Basin refuse, is in a class by itself with regard to ease of removal from the coal during dynamic leaching. Nickel, zinc, cadmium, and manganese fall into the next group, which have EAFs in the range of 45 to 55. These elements were similarly leached from the refuse samples that we studied. Next, in terms of relative leachabilities, is a large group of elements having EAFs in the range of about 5 through 20. This group includes calcium, magnesium, and iron, as well as uranium, thorium, and most of the rare earth elements. Finally at the low end of this leachability scale are aluminum, lead, potassium, and vanadium. This general order of leachabilities is remarkably close to that observed under similar conditions for the Illinois Basin refuse samples.

Subtask 4.3—Assess the Potential For Environmental Contamination From the Trace Elements and Organic Matter in the Aqueous Discharges From Stored Coal

The major effort in this subtask involved compiling and interpreting the information obtained from our studies of the composition and environmental behavior of an Illinois Basin coal. By assessing our experimental data, we have identified the trace elements in the coal sample most likely to cause environmental harm when released into the drainage or runoff from coal storage piles. Although this assessment of potential environmental problems is based on experimental evidence from only one variety of coal, the general correspondence between its elemental leachability and the trace element behavior for the Illinois Basin refuse samples that we studied lends increased weight to the generality of our results for Illinois Basin coals.

The trace elements of most environmental concern in the coal sample were determined by the same process used in Task 3 for the refuse materials. For reasons outlined in Task 3, we chose initial leachates obtained from both the static and dynamic leaching tests of the coal sample with which to make our environmental assessment. Without again going into great detail, the criteria used for choosing the trace elements of concern in the coal or refuse leachates were (1) The element had to be generally known to be toxic to specific plants or animals in aqueous systems or soils in quantities comparable to those present in the coal leachates; (2) The element must have been present in the initial static or dynamic coal leachates in concentrations greater than 10 µg/g of coal or 10 µg/g of leachate, respectively; and/or (3) The trace elements in question must have possessed 10% or greater leachability or EAF greater than 10.

The static and dynamic leaching data for the Illinois Basin coal, which were used in our final deliberations of trace elements of environmental concern, have been condensed from Appendix N into Tables LI (elemental composition of initial static leachate), LII (release percentages of initial static leachate), LIII (elemental concentration of initial dynamic leachate), and LIV (EAFs

TABLE LI

ELEMENTAL COMPOSITION OF LEACHATES FROM STATIC LEACHING EXPERIMENT WITH PLANT E ILLINOIS BASIN COAL

Experiment No. SCL - 1[a]

Leachate Concentration, µg/g coal[b]	Element
> 500	Ca, Fe*
100 - 500	
10 - 100	Na, Mg, Al*, Mn*, Ni*
< 10	K, Sc, V, Cr, Co, Cu, Zn, Ga, As, Br, Rb, Ag, Cd, Sb, Ce, La, Sm, Eu, Dy, Yb, Lu, Hf, Ta, W, Hg, Pb, Th, U

---

* Of environmental concern.

[a] Conditions: -20 mesh coal, unlimited air, room temperature.

[b] pH = 3.1.

TABLE LII

RELEASE PERCENTAGES OF ELEMENTS DURING STATIC LEACHING EXPERIMENT WITH PLANT E ILLINOIS BASIN COAL

Experiment No. SCL - 1[a]

% Release of Original in Coal[b]	Element
> 25	Ca, Mn*, Co*, Ni*, Zn*, Cd*
10 - 25	Sm, Eu, Dy, U
1 - 10	Na, Mg, Sc, Fe, Yb, Lu, Pb
< 1	Al, K, V, Cr, Cu, As

* Of environmental concern.

a Conditions: - 20 mesh coal, unlimited air, room temperature.

b pH = 3.1.

TABLE LIII

ELEMENTAL COMPOSITION OF LEACHATES FROM CONTINUOUS LEACHING EXPERIMENT WITH PLANT E ILLINOIS BASIN COAL

Experiment No. CL-7[a]

Leachate Concentration μg/ml Leachate[b]	Element
> 500	Fe*
100 - 500	Al*, Ca
10 - 100	Na, Mg, Mn*, Co*, Ni*, Zn*
< 10	K, Sc, V, Cr, Cu, Ga, As, Br, Rb, As, Cd, Sb, Cs, La, Ce, Sm, Eu, Dy, Yb, Lu, Hf, Ta, W, Hg, Pb, Th, U

* Of environmental concern.

a Conditions: - 3/8-in. coal, 200 ml leachate, room temperature.

b pH = 2.2.

TABLE LIV

ENVIRONMENTAL ACTIVITY FACTORS FROM CONTINUOUS LEACHING EXPERIMENT WITH PLANT E ILLINOIS BASIN COAL

Experiment No. CL-7[a]

Leachate Environmental Activity Factor[b]	Element
> 25	Mn*, Co*, Ni*, Zn*, Cd*
10 - 25	Mg, Ca, Fe*, Cu*, Sm Eu, Dy, Th
1 - 10	Na, Sc, V, La, Ce Yb, Lu, U
< 1	Al, K, Cr, Pb

---

* Of environmental concern.

[a] Conditions: - 3/8-in. coal,200 ml leachate, room temperature.

[b] pH = 2.2.

TABLE LV

TRACE ELEMENTS OF ENVIRONMENTAL CONCERN IN ILLINOIS BASIN PLANT E COAL

Element	Static Leaching	Dynamic Leaching
Al	x	x
Mn	x	x
Fe	x	x
Co	x	x
Ni	x	x
Zn	x	x
Cd	x	x

of initial dynamic leachate). The elements that meet both the toxicity and leachability requirements in these four tables have been identified with an asterisk.

A single listing of the trace elements of greatest environmental concern in the Plant E coal appears in Table LV. A comparison of the information in this table with similar data in Table XXXIX for the Illinois Basin refuse samples reveals that a nearly identical set of elements has been identified as being of most environmental concern in the coal and refuse materials. From this we conclude that the trace elements in crushed samples of both Illinois Basin coal and coal refuse behave nearly identically when subjected to similar kinds of weathering and leaching.

Unfortunately, in our brief study, we did not learn a great deal about the identities of the organic compounds released from the coal sample during aqueous leaching. As we reported earlier, the total organic content of the coal leachates is on the order of 5 to 50 μg/ml of leachate. How environmentally harmful this level of organic contaminants may be will depend upon the nature of the individual constituents. Organic compounds vary widely in their known or suspected toxicity, carcinogenicity, etc. The question concerning organic contamination of coal leachates will remain unanswered until a more detailed study of the various contaminants is completed.

PERSONNEL

A large number of LASL personnel participated in the programmatic effort during the year. Their work and contributions are gratefully acknowledged.

Administrative Advisors: R. D. Baker, R. J. Bard, and R. C. Feber
Analytical Advisors: G. R. Waterbury and M. E. Bunker
Neutron-Activation Analyses: W. K. Hensley
Atomic Absorption Spectrophotometry and Wet Chemistry:
    E. J. Cokal, L. E. Thorn, and W. H. Ashley
Spectrochemical Analyses: O. R. Simi, J. V. Pena, and D. W. Steinhaus
Electron and Ion Microprobe: W. F. Zelezny, N. E. Elliot,
    W. B. Hutchinson, W. O. Wallace, R. Raymond, and R. C. Gooley
X-ray Diffraction Analyses: R. B. Roof and J. A. O'Rourke
Optical and SEM Microscopy: R. D. Reiswig and L. S. Levinson
Mass Spectrometry: E. D. Loughran
Statistical Evaluation: R. J. Beckman

APPENDIX A

STANDARD PROCEDURE FOR X-RAY MINERALOGICAL ANALYSIS OF COAL AND WASTE MATERIALS

Standard minerals used for calibration were ground to −325 mesh by hand with a mortar and pestle and were mixed with alumina as the internal standard. (Magnesium oxide was also an acceptable internal standard, except for reactive minerals like calcite, gypsum, and iron sulfate.) Glass beads (−325 mesh) were used as diluent for the mineral standards. This provided a means to measure the x-ray patterns of these materials over a range of concentrations. Typical mixtures for instrument calibration contained 0.4000 g of alumina (20%) and 1.6000 g of mineral standard plus diluent. The diluent/mineral mixtures were blended for several minutes on a wigglebug before analysis.

Coal and waste samples were prepared for analysis by crushing them to −20 mesh. Where the samples contained substantial amounts of carbon, they were ashed before analysis with a low-temperature, oxygen plasma (LTA). The −20-mesh materials were further ground to −325 mesh, mixed with alumina (20 wt%), and blended on a wigglebug before analysis.

The powders were placed in the 2.22-cm- (7/8-in.-) diam by 0.15-cm- (1/16-in.-) deep cavity of a 2.54-cm- (1-in.-) diam aluminum holder and pressed smooth with a glass plate. Before placing the holder into the x-ray unit, each sample was glycolated for 1-1/2 h by placing it in a vessel containing the saturated vapor from ethoxyethanol (monoethylglycol) at 50°C. After this treatment, which was done to enhance some of the clay components, each sample was again pressed gently into the holder with a glass plate and analyzed.

A Norelco-Philips diffractometer equipped with an x-ray generating source was used to analyze the mineral contents of the powdered samples. The instrument was operated at 40 kV and 20 mA, using a copper target. The diffractometer was driven at 1 degree/min from $2\theta = 4$ degrees to $2\theta = 60$ degrees. The x-ray intensity response of the nonrotating sample was obtained from a strip chart recorder. Noise levels and peak heights were then determined by visual inspection.

A computer program was used to determine the percentage of minerals in the coal and refuse samples. This program employed second-degree equations for each mineral standard. Matrix and equipment corrections were based on the internal standard. A correction for iron fluorescence, and an estimate of the error in the mineral percentages based on noise level were also obtained by computer calibration.

APPENDIX B

SUMMARY OF LASL COAL AND REFUSE SAMPLE ANALYSES (1)

9-30-77

LOCALE	IDENTITY (2)	SIZE (3)	SAMPLE	LTA	CHN ANAL	MINE-RALOGY	TRACE ELEMENTS	FLOAT SINK
PLANT A	FEED COAL A	28KG	13	YES	YES	YES	YES	NA
A	FEED COAL B	30KG	14	YES	YES	YES	YES	NA
A	CLEAN COAL	6KG	15	YES	YES	YES	YES	NA
A	GOB A-FRESH	65KG	25	YES	YES	YES	YES	NA
A	GOB B-FRESH	73KG	11	YES	YES	YES	YES	NA
A	GOB C-FRESH	71KG	12	YES	YES	YES	YES	NA
A	GOB D-FRESH	73KG	10	YES	YES	YES	YES	NA
A	GOB E-FRESH	70KG	28	YES	YES	YES	YES	NA
A	GOB A,C,E AVE		25A	YES	YES	YES	YES	YES
A	GOB OCCAS LG PC	20KG	16	YES	YES	YES	YES	NA
A	GOB 1Y TOP 3IN	31KG	8	YES	YES	YES	YES	NA
A	GOB 1Y 24IN BELO SURF	37KG	9	YES	YES	YES	YES	NA
PLANT B	FEED COAL	30KG	30	YES	YES	YES	YES	NA
B	PRODUCT COAL-FINE CUT	29KG	31	YES	YES	YES	YES	NA
B	PRODUCT COAL-COARSE CUT	29KG	29	YES	YES	YES	YES	NA
B	GOB A FRESH-DUMPED	47KG	24	YES	YES	YES	YES	NA
B	GOB B FRESH-DUMPED	49KG	17	YES	YES	YES	YES	NA
B	GOB C FRESH-DUMPED	51KG	23	YES	YES	YES	YES	NA
B	GOB A,B,C AVE		24A	YES	YES	YES	YES	YES
B	GOB A TYPE 2	61KG	26	YES	YES	YES	YES	NA
B	GOB B TYPE 2	54KG	27	YES	YES	YES	YES	NA
B	DRY STREAM AT 8Y GOB PILE	10KG	5	YES	YES	YES	YES	NA
B	GOB PILE-8Y AT FOOT	16KG	6	YES	YES	YES	YES	NA
B	SLURRY POND	10KG	4	YES	YES	YES	YES	NA
PLANT C	FEED COAL A	30KG	32	YES	YES	YES	YES	NA
C	FEED COAL B	34KG	33	YES	YES	YES	YES	NA
C	FEED COAL TYPE 2	33KG	35	YES	YES	YES	YES	NA
C	GOB A COARSE-FRESH	51KG	18	YES	YES	YES	YES	NA
C	GOB B COARSE-FRESH	59KG	21	YES	YES	YES	YES	NA
C	GOB C COARSE-FRESH	55KG	22	YES	YES	YES	YES	NA
C	GOB A,B,C, AVE		18A	YES	YES	YES	YES	YES
C	GOB FINE-FRESH	48KG	20	YES	YES	YES	YES	NA
C	GOB VERY FINE-FRESH	24KG	19	YES	YES	YES	YES	NA
PLANT E	FEED COAL A	38KG	36	YES	NA	YES	YES	NA
E	FEED COAL B	41KG	37	YES	NA	YES	YES	NA
E	FEED COAL A,B AVE		36A	YES	NA	YES	YES	NA

TOTAL NUMBER OF SAMPLES = 36

FOOTNOTES

(1) YES=ANALYSIS DONE, NA=NO ANALYSIS IS TO BE DONE

(2) DESIGNATIONS A,B,C, ETC INDICATE THE ORDER IN WHICH SAMPLES WERE COLLECTED: A, FIRST; B, SECOND; ETC. Y=AGE OF MATERIALS IN YEARS

(3) SAMPLE WEIGHTS IN KILOGRAMS; SAMPLE PARTICLE SIZE IN MINUS(-) OR PLUS(+) MESH (SAMPLE 7) AND INCHES (ALL OTHERS); -1 1D INDICATES MINUS 1 INCH IN ONE DIRECTION AND -2 INCHES IN THE OTHERS

TRACE ELEMENT AND MINERAL CONTENT OF COAL WASTE MATERIALS

FOR ILLINOIS BASIN PLANT A SAMPLES

SAMPLE	13	14	15		16	8	9
(1)							
IDENTITY	FED COAL A	FED COAL B	CLN COAL		GOB LRG	GOB TP3 1Y	GOB D24 1Y
LOCALE	PLANT A	PLANT A	PLANT A		PLANT A	PLANT A	PLANT A
DATE OBTND	11/10/75	11/18/75	11/18/75			11/18/75	11/10/75
PCT H2O	7.00	4.42	6.77		1.67	12.24	6.43
PCT LTA	40.57	38.67	18.49		96.11	85.20	83.90
PCT HTA	30.10	29.44	9.47		86.80	71.50	74.10
PCT ORIGNL	100.00	100.00	100.00		100.00	100.00	100.00
SIZE, KG	27.70	29.60	6.00		19.70	31.20	37.40
CHNS ANAL	RAW BASIS	RAW BASIS	RAW BASIS		RAW BASIS	RAW BASIS	RAW BASIS
CARBON	52.20	51.00	68.20		7.50	12.61	13.55
HYDROGEN	4.02	4.12	5.36		.81	1.42	1.40
NITROGEN	1.05	1.03	1.48		.12	.28	.28
SULFUR	3.11	4.27	2.84		8.08	6.99	10.60
MINERALOGY	RAW BASIS	RAW BASIS			RAW BASIS	RAW BASIS	RAW BASIS
KAOLINITE	8.74	10.19			21.17	8.84	9.88
ILLITE	10.27	11.08			13.45	15.93	15.46
QUARTZ	11.77	6.37			21.16	27.77	26.05
PYRITE	6.63	9.56			17.24	6.38	15.00
SPHALERITE							
CALCITE	5.55	1.95			27.73	2.00	1.26
MIXED CLAY	.36				1.67	11.75	
MARCASITE					2.15	4.95	12.66
GYPSUM					.78	8.25	4.01
ROZENITE							
ALBITE							

SAMPLE	13	14	15		16	8	9
ELEMENT (2)	RAW BASIS	RAW BASIS	RAW BASIS		RAW BASIS	RAW BASIS	RAW BASIS
LI PPM H A	53.00	32.00	16.00		33.00	27.00	27.00
BE PPM H A	3.30	3.10	3.40			1.70	1.30
B PPM L E	73.00	56.00	46.00		53.00	63.00	65.00
F PPM R O	250.00	300.00	84.00		290.00	1140.00	691.00
NA PCT H A	.07	.05	.05		.10	.14	.14
MG PCT H A	.21	.14	.06		.54	.36	.44
AL PCT H A	2.90	3.30	1.00		6.70	7.00	6.40
SI PCT R O	6.25	6.62	1.69		13.20	16.30	15.80
P PPM R O	330.00	680.00	135.00		600.00	970.00	12.00
CL PPM R N	40.00	39.00	66.00				24.00
K PCT H A	.53	.56	.10		1.42	1.45	1.30
CA PCT H A	1.55	.55	.15		11.12	.75	1.91
SC PPM R N	8.80	8.00	5.10		9.90	9.10	10.00
TI PCT R N	.21	.21	.08		.47	.35	.42
V PPM R N	69.00	69.00	51.00		47.00	72.00	72.00
CR PPM H A	40.00	35.00	30.00		56.00	87.00	85.00
MN PPM H A	132.50	75.00	31.50		573.50	237.50	442.00
FE PCT H A	2.43	3.17	1.43		7.14	6.84	8.91
CO PPM R N	15.00	13.00	9.00		10.00	3.40	13.00
NI PPM L E	34.00	30.00	18.00		24.00	20.00	46.00
CU PPM H A	56.00	24.00	45.00		39.00	16.00	34.00
ZN PPM H A	130.00	48.00	220.00		34.00	69.00	81.00
GA PPM R N	14.00	15.00	7.00		19.00	18.00	20.00
GE PPM L E	6.90	11.00	11.00		3.80	-9.00	-8.00
AS PPM R N	30.00	20.00	10.00		23.00	16.00	35.00
SE PPM R N	5.00	4.00	4.00		4.20	10.00	6.80
BR PPM R N	.30		1.50				
RB PPM R N	94.00	66.00	77.00		210.00	64.00	100.00
Y PPM L E	15.00	14.00	9.00		39.00	18.00	23.00
ZR PPM L E	65.00	61.00	28.00		180.00	95.00	100.00
MO PPM L E	10.00	14.00	8.00		13.00	29.00	35.00
AG PPM R N						1.40	2.70
CD PPM H A	.20	.30	.20		.19	.10	.50
SN PPM L E	-5.00	-5.00	-3.00		-9.00	-9.00	-8.00
SB PPM R N	1.00	-1.00	1.00			1.40	2.70
CS PPM R N	3.20	4.20	1.30		7.00	5.30	5.10
LA PPM R N	31.00	29.00	11.00		40.00	46.00	39.00
CE PPM R N	61.00	55.00	23.00		84.00	86.00	77.00
SM PPM R N	5.60	4.60	1.70		6.60	4.70	7.30
EU PPM R N	1.10	.90	.40		1.30	.99	1.10
TB PPM R N	1.00						
DY PPM R N	4.00	4.10	2.10		5.20	4.10	4.90
YB PPM R N	2.80	2.20	1.50		2.00	1.80	2.30
LU PPM R N	.39	.28	.17		.40	.47	.41
HF PPM R N	1.90	1.60	1.10		3.10	3.20	3.10
TA PPM R N	.80					.40	.75
W PPM R N	.50					6.00	
HG PPM R N							
PB PPM H A	20.00	21.00	11.00		27.00	32.00	36.00
TH PPM R O	7.30	6.50	2.90		10.80	10.00	10.00
U PPM R O	3.60	3.80	2.10		3.20	9.80	5.40

TRACE ELEMENT AND MINERAL CONTENT OF COAL WASTE MATERIALS

FOR ILLINOIS BASIN PLANT A SAMPLES

SAMPLE	25	11	12	10	28		
(1)							
IDENTITY	GOB A	GOB B FRSH	GOB C FRSH	GOB D FRSH	GOB E		
LOCALE	PLANT A	PLANT A	PLANT A	PLANT A	PLANT A		
DATE OBTND	11/18/75	11/18/75	11/18/75	11/18/75	11/18/75		
PCT H2O	5.91	6.09	6.15	6.23	6.17		
PCT LTA	85.46	85.70	80.78	84.87	86.04		
PCT HTA	78.70	73.60	69.00	73.60	76.70		
PCT ORIGNL	100.00	100.00	100.00	100.00	100.00		
SIZE,KG	64.70	73.20	70.70	72.90	70.20		
CHNS ANAL	RAW BASIS	RAW BASIS	RAW BASIS	RAW BASIS	RAW BASIS		
CARBON	14.60	14.10	17.30	13.70	13.20		
HYDROGEN	1.25	1.28	1.47	1.11	1.25		
NITROGEN	.31	.31	.39	.30	.27		
SULFUR	8.28	10.86	10.41	9.16	6.62		
MINERALOGY	RAW BASIS	RAW BASIS	RAW BASIS	RAW BASIS	RAW BASIS		
KAOLINITE	13.74	14.52	13.44	16.02	15.36		
ILLITE	12.82	12.12	10.78	15.36	19.48		
QUARTZ	21.20	20.40	18.24	22.27	25.64		
PYRITE	14.49	15.79	14.71	13.52	12.72		
SPHALERITE							
CALCITE	10.39	5.22	2.38	1.36	5.24		
MIXED CLAY	4.64	3.47	9.53	7.96	6.39		
MARCASITE	9.03	13.68	11.57	9.68			
GYPSUM	2.60	2.25	2.22	1.80	2.97		
ROZENITE							
ALBITE							

SAMPLE ELEMENT	25 RAW BASIS	11 RAW BASIS	12 RAW BASIS	10 RAW BASIS	28 RAW BASIS	----------	----------
LI PPM H A (2)	36.00	55.00	55.00	59.00	51.00		
BE PPM H A							
B PPM L E	67.00	55.00	64.00	54.00	70.00		
F PPM R O	666.00	400.00	620.00	733.00	730.00		
NA PCT H A	.10	.10	.10	.12	.11		
MG PCT H A	.44	.36	.34	.40	.51		
AL PCT H A	6.90	6.50	6.90	7.40	7.30		
SI PCT R O	13.44	13.14	13.50	15.14	16.40		
P PPM R O	2500.00	1100.00	2500.00	3300.00	2300.00		
CL PPM R N	20.00			37.00	32.00		
K PCT H A	1.15	1.05	1.04	1.33	1.19		
CA PCT H A	6.31	4.50	2.84	2.41	4.25		
SC PPM R N	11.20	11.60	11.60	13.40	13.10		
TI PCT R N	.42	.44	.47	.50	.47		
V PPM R N	72.00	74.00	78.00	87.00	81.00		
CR PPM H A	54.00	57.00	52.00	70.00	66.00		
MN PPM H A	418.50	313.00	235.00	233.50	304.00		
FE PCT H A	7.20	9.40	8.90	8.40	6.24		
CO PPM R N	20.00	20.00	18.00	18.00	19.00		
NI PPM L E	50.00	43.00	48.00	40.00	37.00		
CU PPM H A	51.00	55.00	51.00	52.00	52.00		
ZN PPM H A	78.00	93.00	74.00	92.00	79.00		
GA PPM R N	17.00	17.00	16.00	23.00	22.00		
GE PPM L E	5.10	3.90	4.30	4.80	7.60		
AS PPM R N	51.00	65.00	53.00	50.00	60.00		
SE PPM R N	9.20	11.00	6.50	11.00	8.80		
BR PPM R N							
RB PPM R N	100.00	130.00	180.00	220.00	250.00		
Y PPM L E	40.00	30.00	39.00	30.00	36.00		
ZR PPM L E	160.00	140.00	160.00	130.00	160.00		
MO PPM L E	11.00	14.00	16.00	12.00	8.10		
AG PPM R N							
CD PPM H A	.25	.30	.20	.30	.16		
SN PPM L E	-9.00	-8.00	-8.00	-8.00	-9.00		
SB PPM R N	1.40		1.50	1.50			
CS PPM R N	6.00	4.50	6.80	6.40	7.10		
LA PPM R N	42.00	41.00	47.00	45.00	49.00		
CE PPM R N	83.00	90.00	90.00	100.00	98.00		
SM PPM R N	7.20	7.60	7.50	6.80	8.10		
EU PPM R N	1.30	1.60	1.50	1.70	1.70		
TB PPM R N							
DY PPM R N	5.80	6.20	6.10	7.30	6.60		
YB PPM R N	2.70	3.30	3.70	3.30	2.40		
LU PPM R N	.40	.40	.40	.50	.50		
HF PPM R N	3.00	3.50	3.30	3.60	3.70		
TA PPM R N		-1.00		3.00			
W PPM R N							
HG PPM R N							
PB PPM H A	60.00	50.00	46.00	50.00	38.00		
TH PPM R O	11.60	12.00	11.50	12.80	13.20		
U PPM R O	6.80	4.60	8.20	7.40	6.90		

TRACE ELEMENT AND MINERAL CONTENT OF COAL WASTE MATERIALS

FOR ILLINOIS BASIN PLANT B SAMPLES

SAMPLE	30	31	29	24	17	23	
IDENTITY (1)	FEED COAL	FN COL PRD	CORS COL P	GOB A	GOB B	GOB C	
LOCALE	PLANT B	PLANT B	PLANT B	PLANT B	PLANT B	PLANT B	
DATE OBTND	11/19/75	11/19/75	11/19/75	11/19/75	11/19/75	11/19/75	
PCT H2O	4.07	9.38	5.32	9.62	10.35	10.38	
PCT LTA	20.25	24.42	21.34	79.80	77.41	79.84	
PCT HTA	10.81	14.06	10.76	64.20	61.30	65.20	
PCT ORIGNL	100.00	100.00	100.00	100.00	100.00	100.00	
SIZE,KG	38.00	28.80	29.50	46.60	49.10	50.60	
CHNS ANAL	RAW BASIS	RAW BASIS	RAW BASIS	RAW BASIS	RAW BASIS	RAW BASIS	
CARBON	59.20	64.30	66.40	18.80	21.40	19.30	
HYDROGEN	4.49	4.67	4.81	2.20	2.30	2.20	
NITROGEN	1.25	1.33	1.34	.42	.45	.42	
SULFUR	3.92	3.08	2.61	14.30	14.70	11.40	
MINERALOGY	RAW BASIS	RAW BASIS	RAW BASIS	RAW BASIS	RAW BASIS	RAW BASIS	
KAOLINITE	4.61	4.21	3.69	7.16	6.38	7.18	
ILLITE	5.02	4.41	3.51	10.40	12.77	8.54	
QUARTZ	5.09	3.03	2.21	19.02	13.90	18.56	
PYRITE	5.31	4.85	4.01	13.61	19.98	12.43	
SPHALERITE							
CALCITE							
MIXED CLAY	2.48	.58	.90	18.76	11.94	21.10	
MARCASITE	1.03	2.19	1.46	9.75	11.19	11.09	
GYPSUM		.11	.06	1.10	1.25	.94	
ROZENITE							
ALBITE							

SAMPLE	30	31	29	24	17	23
ELEMENT (2)	RAW BASIS	RAW BASIS	RAW BASIS	RAW BASIS	RAW BASIS	RAW BASIS
LI PPM H A	19.00	15.00	8.00	52.00	58.00	47.00
BE PPM H A	1.50	1.60	1.40	2.80	2.40	3.10
B PPM L E	53.00	51.00	58.00	64.00	63.00	65.00
F PPM R O	161.00	133.00	130.00	346.00	366.00	410.00
NA PCT H A	.03	.03	.02	.07	.08	.09
MG PCT H A	.09	.07	.05	.21	.24	.31
AL PCT H A	2.10	1.50	1.30	5.03	4.94	5.29
SI PCT R O	3.92	2.52	1.99	13.20	12.90	14.60
P PPM R O	320.00	280.00	270.00			
CL PPM R N	120.00	160.00	11.00	42.00	53.00	76.00
K PCT H A	.40	.30	.24	1.07	1.07	1.21
CA PCT H A	.05	.06	.08	.10	.09	.13
SC PPM R N	5.70	4.50	4.10	13.00	11.00	12.00
TI PCT R N	.13	.10	.08	.33	.36	.36
V PPM R N	44.00	40.00	29.00	78.00	85.00	95.00
CR PPM H A	27.00	149.00	30.00	56.00	59.00	72.00
MN PPM H A	39.00	107.50	33.00	143.50	130.00	159.50
FE PCT H A	2.57	1.82	1.25	12.80	10.80	9.30
CO PPM R N	10.00	9.00	7.00	35.00	30.00	25.00
NI PPM L E	20.00	16.00	9.50	73.00	73.00	68.00
CU PPM H A	11.60	64.00	31.00	32.40	35.00	38.80
ZN PPM H A	43.00	183.00	100.00	117.00	197.00	133.00
GA PPM R N	9.00	8.00	7.00			
GE PPM L E	3.60	5.20	3.80	-8.00	-8.00	-8.00
AS PPM R N	22.00	8.00	5.00	130.00	89.00	64.00
SE PPM R N		3.00	2.00	8.00	5.[illegible]	4.80
BR PPM R N	2.50	2.50	2.50	2.00	2.00	2.00
RB PPM R N	69.00	45.00	20.00	81.00	97.00	110.00
Y PPM L E	8.20	6.80	5.10	15.00	17.00	21.00
ZR PPM L E	48.00	43.00	27.00	82.00	80.00	100.00
MO PPM L E	6.80	5.00	3.70	57.00	53.00	47.00
AG PPM R N				.40	.50	.60
CD PPM H A	.12	.08	.13	.35	.50	.39
SN PPM L E	-4.00	-3.00	-4.00	-8.00	-8.00	-8.00
SB PPM R N	1.50	-1.00	-1.00	1.70	1.30	1.10
CS PPM R N	2.90			7.10	5.80	6.80
LA PPM R N	15.00	12.00	6.00	43.00	31.00	37.00
CE PPM R N	28.00	19.00	17.00	88.00	61.00	71.00
SM PPM R N	2.30	1.60	1.30	7.00	4.80	5.90
EU PPM R N	.50	.40	.30	1.40	1.00	1.30
TB PPM R N			.40			
DY PPM R N	2.10	1.40	1.10	4.40	4.40	4.30
YB PPM R N	1.40	.90		2.50	2.80	4.40
LU PPM R N	.14	.10	.10	.47	.37	.38
HF PPM R N	1.40	1.10	1.10	3.70	2.40	3.30
TA PPM R N	.80	.60		.94	.78	1.10
W PPM R N	.60	.60				
HG PPM R N						
PB PPM H A	13.00	12.00	7.00	31.00	36.00	34.00
TH PPM R O	3.10	2.50	2.20	11.00	8.40	9.10
U PPM R O	1.10	.90	.70	2.70	2.70	2.70

TRACE ELEMENT AND MINERAL CONTENT OF COAL WASTE MATERIALS

FOR ILLINOIS BASIN PLANT B SAMPLES

SAMPLE	26	27	5	6	4		7A
IDENTITY (1)	GOB A	GOB B	DRY STM 8Y	GOB PIL 8Y	SLURY POND		GOB/WH -6
LOCALE	PLANT B	PLANT B	PLANT B	PLANT B	PLANT B		PLANT B
DATE OBTND	11/19/75	11/19/75	11/19/75	11/19/75	11/19/75		11/19/75
PCT H2O	6.01	4.77	7.83	7.83	22.10		
PCT LTA	88.44	90.58	68.58	79.90	69.37		
PCT HTA	69.50	71.24	56.50	67.40	58.10		
PCT ORIGNL	100.00	100.00	100.00	100.00	100.00		1.60
SIZE,KG	60.90	54.20	9.50	16.30	9.70		.40
CHNS ANAL	RAW BASIS	RAW BASIS	RAW BASIS	RAW BASIS	RAW BASIS		
CARBON	10.70	11.00	17.00	13.70	22.54		
HYDROGEN	1.37	1.25	2.12	1.34	1.88		
NITROGEN	.22	.25	.56	.31	.47		
SULFUR	21.40	16.00	3.95	14.10	11.10		
MINERALOGY	RAW BASIS	RAW BASIS	RAW BASIS	RAW BASIS	RAW BASIS		
KAOLINITE	9.89	9.80	10.81	6.30	8.96		
ILLITE	12.43	9.04	9.64	6.89	9.39		
QUARTZ	17.22	21.47	24.25	15.19	19.52		
PYRITE	23.47	24.00	1.50	11.01	17.12		
SPHALERITE							
CALCITE							
MIXED CLAY	6.32	7.26	20.54	13.75	5.92		
MARCASITE	15.10	16.95		10.24	8.01		
GYPSUM	4.01	2.06		4.03	2.08		
ROZENITE							
ALBITE							

SAMPLE	26	27	5	6	4		7A
ELEMENT (2)	RAW BASIS	RAW BASIS	RAW BASIS	RAW BASIS	RAW BASIS		RAW BASIS
LI PPM H A	18.00	35.00	34.00	54.00	21.00		
BE PPM H A	1.80	1.80	1.60	.90	1.90		
B PPM L E	85.00	85.00	83.00	80.00	57.00		
F PPM R O	540.00	570.00	341.00	790.00	400.00		
NA PCT H A	.10	.06	.10	.09	.06		.04
MG PCT H A	.18	.20	.14	.14	.20		
AL PCT H A	5.90	6.60	6.40	5.90	5.30		
SI PCT R O	10.98	13.98	15.80	15.20	11.30		
P PPM R O	1625.00	1630.00	410.00	12.00	10.00		
CL PPM R N	30.00	20.00	59.00		57.00		39.00
K PCT H A	.97	1.16	.90	1.01	.89		
CA PCT H A	.92	.61	.08	.45	.46		.27
SC PPM R N	8.10	9.90	6.90	6.40	7.40		3.80
TI PCT R N	.33	.31	.41	.40	.26		.13
V PPM R N	39.00	38.00	54.00	46.00	61.00		22.00
CR PPM H A	41.00	47.00	75.00	67.00	62.00		
MN PPM H A	159.00	156.50	37.00	119.00	213.00		77.00
FE PCT H A	17.43	12.97	2.84	10.30	10.10		
CO PPM R N	25.00	20.00	.94	2.10	21.00		6.40
NI PPM L E	71.00	61.00	9.40	13.00	80.00		
CU PPM H A	35.00	35.00	11.00	13.00	62.00		
ZN PPM H A	103.00	72.00	20.00	27.00	197.00		
GA PPM R N	13.00	15.00	16.00	6.60	18.00		9.70
GE PPM L E	-9.00	-9.00	-7.00	-8.00	-7.00		
AS PPM R N	30.00	20.00	15.00	15.00	72.00		76.00
SE PPM R N	6.00	5.00	6.00	5.80	7.50		6.10
BR PPM R N			.86		2.50		
RB PPM R N	250.00	230.00	93.00	110.00	150.00		150.00
Y PPM L E	19.00	18.00	11.00	12.00	15.00		
ZR PPM L E	110.00	120.00	64.00	77.00	78.00		
MO PPM L E	42.00	40.00	24.00	39.00	27.00		
AG PPM R N			1.40	5.80	3.90		
CD PPM H A	.41	.61	-.10	.10	.70		
SN PPM L E	-9.00	-9.00	-7.00	-8.00	-7.00		
SB PPM R N	-1.00	-1.00	1.70	1.50	2.40		
CS PPM R N	4.90	6.20	5.60	3.70	4.00		2.20
LA PPM R N	33.00	43.00	45.00	49.00	25.00		12.00
CE PPM R N	83.00	96.00	80.00	81.00	55.00		23.00
SM PPM R N	7.00	8.10	4.40	4.60	4.40		2.00
EU PPM R N	1.60	1.70	.78	.79	.88		.35
TB PPM R N	.60	.70					
DY PPM R N	5.20	4.80	2.20	2.50	3.30		1.60
YB PPM R N	2.40	2.60	1.70	1.60	1.40		.70
LU PPM R N	.40	.39	.30	.31	.27		.21
HF PPM R N	2.80	3.90	3.90	3.40	3.40		.89
TA PPM R N	7.40	1.10	.60	.60	.44		.11
W PPM R N	3.00	.60	8.00		4.00		
HG PPM R N							
PB PPM H A	48.00	19.00	20.00	22.00	37.00		
TH PPM R O	9.80	12.00	7.00	8.60	7.90		3.50
U PPM R O	2.40	2.80	2.60	4.80	3.90		1.60

TRACE ELEMENT AND MINERAL CONTENT OF COAL WASTE MATERIALS

FOR ILLINOIS BASIN PLANT C SAMPLES

SAMPLE (1)	32	33	34	35	18	21	22	20	19
IDENTITY	RAW COAL A	RAW COAL B	CLEAN COAL	COAL TYP 2	GOB A CORS	GOB B CORS	GOB C CORS	FN GOB	GOB V FINE
LOCALE	PLANT C	PLANT C	PLANT C	PLANT C	PLANT C	PLANT C	PLANT C	PLANT C	PLANT C
DATE OBTND	11/20/75	11/20/75	11/20/75	11/20/75	11/20/75	11/20/75	11/20/75	11/20/75	11/20/75
PCT H2O	3.75	3.59	4.06	3.92	3.26	3.88	2.92	7.92	10.00
PCT LTA	29.90	37.35	14.45	35.60	92.97	90.56	91.85	84.39	79.80
PCT HTA	25.15	32.79	10.61	31.00	80.10	76.30	83.80	71.70	70.50
PCT ORIGNL	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
SIZE, KG	30.20	34.50	27.20	32.60	51.10	50.40	54.90	48.10	23.70
CHNS ANAL	RAW BASIS	RAW BASIS	RAW BASIS	RAW BASIS	RAW BASIS	RAW BASIS	RAW BASIS	RAW BASIS	RAW BASIS
CARBON	54.00	49.10	67.90	52.20	7.20	9.40	8.30	13.50	17.70
HYDROGEN	4.10	3.81	5.24	3.94	.90	1.05	1.37	1.55	1.41
NITROGEN	1.00	.83	1.23	1.01	.19	.25	.24	.29	.36
SULFUR	6.43	4.05	3.55	3.95	10.31	15.13	12.14	12.81	7.93
MINERALOGY	RAW BASIS	RAW BASIS	RAW BASIS	RAW BASIS	RAW BASIS	RAW BASIS	RAW BASIS	RAW BASIS	RAW BASIS
KAOLINITE	5.04	7.83	.77	4.05	15.36	14.12	13.45	10.18	10.47
ILLITE	4.88	8.92	2.81	13.35	15.39	14.98	16.89	13.84	15.93
QUARTZ	5.75	11.89	3.57	6.63	24.01	20.02	24.83	22.56	21.91
PYRITE	9.81	7.42	4.82	5.87	17.94	26.43	20.43	22.19	14.77
SPHALERITE									
CALCITE	.74	.57	.07	2.42	1.31			.08	2.53
MIXED CLAY	.50	1.15	.32	.59	14.26	2.27	6.94	4.79	8.70
MARCASITE	3.10	2.95	1.79	1.78	5.14	11.37	9.30	8.62	5.74
GYPSUM	.23		.27			1.38		2.17	.56
ROZENITE									
ALBITE									

SAMPLE	32	33	34	35	10	21	22	20	19
ELEMENT (2)	RAW BASIS	RAW BASIS	RAW BASIS	RAW BASIS	RAW BASIS	RAW BASIS	RAW BASIS	RAW BASIS	RAW BASIS
LI PPM H A	9.00	10.00	13.00	14.00	22.00	16.00	13.00	7.00	16.00
BE PPM H A	2.10	2.00	1.70	1.50					
B PPM L E	60.00	72.00	37.00	62.00	80.00	68.00	84.00	78.00	87.00
F PPM R O	232.00	340.00	164.00	282.00	1580.00	1670.00	1130.00	936.00	970.00
NA PCT H A	.12	.17	.04	.15	.37	.26	.32	.27	.30
MG PCT H A	.11	.13	.06	.33	.33	.22	.28	.36	.40
AL PCT H A	2.30	3.60	1.00	2.00	8.70	6.10	8.30	6.60	7.10
SI PCT R O	5.03	8.02	2.29	6.90	17.40	15.20	17.07	15.06	16.34
P PPM R O	490.00	615.00	270.00	455.00	5000.00	7300.00	4300.00	2000.00	2700.00
CL PPM R N	460.00	310.00	490.00	450.00	90.00	86.00	88.00	110.00	170.00
K PCT H A	.43	.58	.21	.79	1.52	.99	1.30	1.50	1.64
CA PCT H A	.45	.52	.13	.89	1.51	1.71	1.02	1.42	1.53
SC PPM R N	5.10	7.00	3.00	6.80	12.10	10.60	10.70	10.40	12.40
TI PCT R N	.14	.24	.07	.15	.54	.44	.48	.40	.46
V PPM R N	34.00	41.00	30.00	100.00	85.00	62.00	68.00	68.00	80.00
CR PPM H A	60.00	30.00	30.00	73.00	80.00	60.00	64.00	63.00	78.00
MN PPM H A	110.50	63.50	31.50	267.00	124.50	101.00	125.50	149.50	161.50
FE PCT H A	4.13	2.60	1.44	3.21	8.90	10.15	10.11	10.20	6.57
CO PPM R N	11.00	17.00	7.00	9.00	32.00	27.00	31.00	21.00	22.00
NI PPM L E	21.00	29.00	9.00	26.00	80.00	52.00	75.00	45.00	41.00
CU PPM H A	44.00	40.00	32.00	31.00	44.00	27.00	37.00	41.00	44.00
ZN PPM H A	153.00	200.00	160.00	100.00	228.00	76.00	57.00	160.00	103.00
GA PPM R N	9.00	13.00	7.00	13.00	16.00	14.00	15.00	21.00	20.00
GE PPM L E	4.50	4.80	5.20	4.90	6.40	4.20	5.00	6.20	5.30
AS PPM R N	9.00	10.00	5.00	15.00	23.00	26.00	20.00	18.00	21.00
SE PPM R N	4.00	3.00		7.00	9.60	9.50	7.00	6.50	8.80
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]					
RB PPM R N	100.00	60.00	46.00	22.00	260.00	300.00	210.00	250.00	270.00
Y PPM L E	9.60	9.10	5.50	10.00	12.00	28.00	24.00	26.00	28.00
ZR PPM L E	54.00	50.00	25.00	58.00	130.00	120.00	120.00	130.00	130.00
MO PPM L E	17.00	16.00	8.70	25.00	13.00	14.00	14.00	13.00	8.10
AG PPM R N									
CD PPM H A	.17	.09	.16	2.10	1.30	1.10	.51	1.50	1.20
SN PPM L E	-4.00	-4.00	-2.00	-4.00	-9.00	-9.00	-9.00	-8.00	-8.00
SB PPM R N	1.70	1.00	.60	2.70	1.20	1.30	1.10	.90	1.20
CS PPM R N	4.00	5.00	1.70	3.20	7.40	9.00	6.70	9.10	7.80
LA PPM R N	17.00	31.00	8.00	20.00	56.00	42.00	47.00	39.00	42.00
CE PPM R N	33.00	60.00	13.00	38.00	100.00	97.00	92.00	76.00	81.00
SM PPM R N	2.40	4.80	1.30	3.20	8.80	7.00	6.90	6.10	7.10
EU PPM R N	.50	1.40	.20	.60	1.60	1.50	1.40	1.40	1.40
TB PPM R N				.70					
DY PPM R N	1.00	2.90	1.10	2.00	6.30	5.20	4.70	4.90	6.00
YB PPM R N	1.00	1.50	.90	1.30	1.90	2.50	2.20	1.80	3.70
LU PPM R N	.20	.26	.12	.23	.40	.40	.40	.30	.30
HF PPM R N	1.30	2.90	.60	1.50	3.80	3.70	4.60	3.30	4.00
TA PPM R N	.30	1.00	.40		1.00	1.20	.90		
W PPM R N		1.20	.50	1.20					
HG PPM R N									
PB PPM H A	13.00	10.00	9.00	15.00	54.00	56.00	59.00	49.00	33.00
TH PPM R O	4.30	8.00	2.20	5.90	13.50	12.20	13.80	10.00	10.80
U PPM R O	1.60	2.10	1.40	4.20	9.90	12.90	7.40	5.70	5.70

TRACE ELEMENT AND MINERAL CONTENT OF COAL WASTE MATERIALS

FOR ILLINOIS BASIN PLANT E SAMPLES

SAMPLE	36	37
(1)		
IDENTITY	FED COAL A	FED COAL B
LOCALE	PLANT E	PLANT E
DATE OBTND	06/22/76	06/22/76
PCT H2O	5.46	4.42
PCT LTA	24.73	25.36
PCT HTA		
PCT ORIGNL	100.00	100.00
SIZE,KG	39.90	43.30
CHNS ANAL	RAW BASIS	RAW BASIS
CARBON		
HYDROGEN		
NITROGEN		
SULFUR	5.27	5.81
MINERALOGY		
KAOLINITE		
ILLITE		
QUARTZ		
PYRITE		
SPHALERITE		
CALCITE		
MIXED CLAY		
MARCASITE		
GYPSUM		
ROZENITE		
ALBITE		

SAMPLE ELEMENT	(2)	36 RAW BASIS	37 RAW BASIS
LI PPM	H A	65.00	63.00
BE PPM	H A	20.00	22.00
B PPM	L E	70.00	62.00
F PPM	R O	80.00	60.00
NA PCT	H A	.03	.03
MG PCT	H A	.06	.05
AL PCT	H A	1.82	1.81
SI PCT	R O	1.40	2.50
P PPM	R O	310.00	260.00
CL PPM	R N	77.00	123.00
K PCT	H A	.26	.23
CA PCT	H A	.15	.21
SC PPM	R N	4.53	4.81
TI PCT	R N	.08	.10
V PPM	R N	37.00	49.70
CR PPM	H A	30.00	21.00
MN PPM	H A	42.10	58.15
FE PCT	H A	3.90	4.70
CO PPM	R N	13.50	13.30
NI PPM	L E	42.00	26.00
CU PPM	H A	38.00	33.00
ZN PPM	H A	32.00	22.00
GA PPM	R N		5.52
GE PPM	L E	-8.00	-7.00
AS PPM	R N	24.20	43.00
SE PPM	R N		
BR PPM	R N	16.00	41.00
RB PPM	R N		
Y PPM	L E	37.00	29.00
ZR PPM	L E	55.00	39.00
MO PPM	L E	25.00	16.00
AG PPM	R N		
CD PPM	H A	.21	.15
SN PPM	L E	-8.00	-7.00
SB PPM	R N	.79	1.38
CS PPM	R N	2.37	
LA PPM	R N	22.10	18.60
CE PPM	R N	34.30	30.50
SM PPM	R N	2.27	2.48
EU PPM	R N	.91	.73
TB PPM	R N		
DY PPM	R N	3.10	3.80
YB PPM	R N	3.08	1.10
LU PPM	R N	.17	.24
HF PPM	R N	.35	1.26
TA PPM	R N		
W PPM	R N		
HG PPM	R N		
PB PPM	H A	11.00	11.00
TH PPM	R O	3.39	3.52
U PPM	R O	2.47	2.64

FOOTNOTES

(1) PLUS OR MINUS INDICATES SIZE GREATER OR LESS THAN SIZE GIVEN. NUMBERS 6 OR LARGER ARE MESH SIZES, OTHERS ARE IN INCHES

(2) LETTERS INDICATE HOW SAMPLE WAS PREPARED AND ANALYZED

R= RAW SAMPLE
L= LOW TEMPERATURE ASH
H= HIGH TEMPERATURE ASH
N= NEUTRON ACTIVATION ANALYSIS
A= ATOMIC ABSORPTION
E= EMISSION SPECTROSCOPY
O= OTHER

APPENDIX C

SUMMARY OF LASL SIZED-COAL REFUSE SAMPLE ANALYSES (1)

9-30-77

LOCALE	IDENTITY (2)	SIZE (3)	SAMPLE	LTA	CHN ANAL	MINERALOGY	TRACE ELEMENTS	FLOAT SINK
PLANT A	GOB A,C,E AVE	-1/4	25B	YES	YES	YES	YES	NA
A		-1	25C	YES	YES	YES	YES	NA
A		-1 1D	25D	YES	YES	YES	YES	NA
A		-2	25E	YES	YES	YES	YES	NA
A		+2	25F	YES	YES	YES	YES	NA
PLANT B	GOB A,B,C AVE	-1/4	24B	YES	YES	YES	YES	YES
B		-1	24C	YES	YES	YES	YES	NA
B		-1 1D	24D	YES	YES	YES	YES	NA
B		-2	24E	YES	YES	YES	YES	NA
B		+2	24F	YES	YES	YES	YES	YES
PLANT C	GOB A,B,C AVE	-1/4	18B	YES	YES	YES	YES	NA
C		-1	18C	YES	YES	YES	YES	NA
C		-1 1D	18D	YES	YES	YES	YES	NA
C		-2	18E	YES	YES	YES	YES	NA
C		+2	18F	YES	YES	YES	YES	NA
C	GOB FINE-FRESH	-1/4	20B	NA	NA	NA	NA	NA
C		-1	20C	NA	NA	NA	NA	NA
C		-1 1D	20D	NA	NA	NA	NA	NA
C		-2	20E	NA	NA	NA	NA	NA
C	GOB VERY FINE-FRESH	-1/4	19B	NA	NA	NA	NA	NA
C		-1	19C	NA	NA	NA	NA	NA
C		-1 1D	19D	NA	NA	NA	NA	NA
C		-2	19E	NA	NA	NA	NA	NA

TOTAL NUMBER OF SAMPLES = 23

FOOTNOTES

(1) YES=ANALYSIS DONE, NA=NO ANALYSIS IS TO BE DONE

(2) DESIGNATIONS A,B,C, ETC INDICATE THE ORDER IN WHICH SAMPLES WERE COLLECTED: A, FIRST; B, SECOND; ETC. Y=AGE OF MATERIALS IN YEARS

(3) SAMPLE PARTICLE SIZE IN MINUS(-) OR PLUS(+) INCHES; -1 1D INDICATES MINUS 1 INCH IN ONE DIRECTION AND -2 INCHES IN THE OTHERS

TRACE ELEMENT AND MINERAL CONTENT OF SIZED WASTE MATERIALS

FOR ILLINOIS BASIN PLANT A SAMPLES

SAMPLE	25B	25C	25D	25E	25F		
(1) IDENTITY	-1/4	-1	-1D	-2	+2		
LOCALE	PLANT A	PLANT A	PLANT A	PLANT A	PLANT A		
DATE OBTND	11/18/75	11/18/75	11/18/75	11/18/75	11/18/75		
PCT H2O							
PCT LTA	86.27	85.98	85.71	83.08	83.85		
PCT HTA	78.50	74.30	73.10	71.50	72.90		
PCT ORIGNL SIZE, KG	18.50	20.20	13.40	10.90	37.00		
CHNS ANAL	RAW BASIS	RAW BASIS	RAW BASIS	RAW BASIS	RAW BASIS		
CARBON	14.10	14.60	14.20	16.20	16.50		
HYDROGEN	1.53	1.70	2.07	1.39	1.76		
NITROGEN	.33	.33	.34	.28	.35		
SULFUR	6.51	7.67	9.49	12.06	10.53		
MINERALOGY	RAW BASIS	RAW BASIS	RAW BASIS	RAW BASIS	RAW BASIS		
KAOLINITE	16.38	13.10	16.72	11.83	10.84		
ILLITE	13.94	12.35	15.83	12.80	8.38		
QUARTZ	26.56	23.28	21.40	19.21	15.20		
PYRITE	11.72	11.52	17.63	20.96	16.97		
SPHALERITE							
CALCITE	-.01	4.76	2.21	9.69	18.59		
MIXED CLAY	10.49	14.80	4.15	2.88	8.32		
MARCASITE	1.60	6.57	6.34	8.26	11.92		
GYPSUM	5.58	1.20	2.39	.68			
ROZENITE							
ALBITE							

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 SAMPLE           25B              25C              25D              25E              25F
--------      ----------       ----------       ----------       ----------       ----------       ----------       ----------
ELEMENT       RAW BASIS        RAW BASIS        RAW BASIS        RAW BASIS        RAW BASIS
           (2)
 LI PPM H A       40.00            33.00            40.00            30.00            31.00
 BE PPM H A
 B  PPM L E       76.00            71.00            64.00            59.00            56.00
 F  PPM R O      750.00           960.00           700.00           530.00           410.00
 NA PCT H A         .11              .11              .12              .10              .10
 MG PCT H A         .41              .43              .37              .41              .42
 AL PCT H A        7.50             7.70             7.60             5.30             6.00
 SI PCT R O       16.60            16.65            15.94            12.55            12.10
 P  PPM R O     2100.00          3100.00          2500.00          1800.00           900.00
 CL PPM R N
 K  PCT H A        1.40             1.37             1.25              .90              .88
 CA PCT H A        2.19             2.69             2.11             5.47             6.75
 SC PPM R N       14.00            13.90            12.70             8.90             9.30
 TI PCT R N         .51              .47              .50              .37              .39
 V  PPM R N       85.00            82.00            85.00            59.00            57.00
 CR PPM H A       72.00            67.00            65.00            39.00            46.00
 MN PPM H A      227.50           255.00           220.50           334.00           382.50
 FE PCT H A        5.76             7.23             8.30             9.95             8.54
 CO PPM R N       19.00            21.00            22.00            17.00            19.00
 NI PPM L E       49.00            48.00            46.00            38.00            39.00
 CU PPM H A       58.00            56.00            62.00            33.00            40.00
 ZN PPM H A      250.00           114.00           400.00            57.00            72.00
 GA PPM R N       21.00            22.00            23.00            15.00            17.00
 GE PPM L E        5.10             6.20             7.70             3.90             5.30
 AS PPM R N       68.00            67.00            79.00            59.00            30.00
 SE PPM R N        8.90            11.00             7.00             5.00             8.10
 BR PPM R N
 RB PPM R N      240.00           320.00           240.00           250.00           160.00
 Y  PPM L E       36.00            36.00            35.00            33.00            34.00
 ZR PPM L E      180.00           150.00           140.00           160.00           160.00
 MO PPM L E        9.00            10.00            12.00            15.00            14.00
 AG PPM R N
 CD PPM H A         .62             2.30             5.10              .10              .10
 SN PPM L E       -9.00            -9.00            -9.00            -8.00            -8.00
 SB PPM R N        1.90             2.20                                               1.10
 CS PPM R N        6.10             7.50             5.70             5.20             3.20
 LA PPM R N       52.00            50.00            50.00            31.00            37.00
 CE PPM R N      110.00           110.00           100.00            59.00            72.00
 SM PPM R N        8.80             8.90             9.00             4.80             5.60
 EU PPM R N        1.80             1.80             1.80             1.10             1.20
 TB PPM R N
 DY PPM R N        6.70             7.10             7.20             4.70             4.80
 YB PPM R N        4.50             3.40             3.60             2.30             2.10
 LU PPM R N         .60              .50              .50              .40              .40
 HF PPM R N        4.90             5.20             3.70             2.80             2.20
 TA PPM R N          50             1.00             1.10
 W  PPM R N
 HG PPM R N
 PB PPM H A       53.00            57.00            56.00            38.00            39.00
 TH PPM R O       12.90            12.80            12.60             7.70             9.80
 U  PPM R O        7.80             2.60             6.60             5.80             4.70
```

TRACE ELEMENT AND MINERAL CONTENT OF SIZED WASTE MATERIALS

FOR ILLINOIS BASIN PLANT B SAMPLES

SAMPLE	24B	24C	24D	24E	24F		
IDENTITY (1)	AVE -1/4	AVE -1	AVE -1D	AVE -2	AVE +2		
LOCALE	PLANT B	PLANT B	PLANT B	PLANT B	PLANT B		
DATE OBTND	11/19/75	11/19/75	11/19/75	11/19/75	11/19/75		
PCT H2O							
PCT LTA	86.30	78.90	80.20	68.80	81.30		
PCT HTA	72.30	65.20	64.60	49.80	60.00		
PCT ORIGNL SIZE, KG	23.80	30.90	12.40	12.50	20.30		
CHNS ANAL	RAW BASIS	RAW BASIS	RAW BASIS	RAW BASIS	RAW BASIS		
CARBON	13.00	20.70	19.60	27.60	17.30		
HYDROGEN	2.00	2.20	2.20	2.50	1.70		
NITROGEN	.30	.45	.43	.56	.38		
SULFUR	8.60	8.50	8.60	13.90	24.40		
MINERALOGY	RAW BASIS	RAW BASIS	RAW BASIS	RAW BASIS	RAW BASIS		
KAOLINITE	9.83	8.69	8.56	5.26	5.14		
ILLITE	14.63	14.71	20.70	9.84	13.17		
QUARTZ	20.70	19.25	22.68	13.42	19.97		
PYRITE	15.03	14.57	16.20	22.41	27.09		
SPHALERITE							
CALCITE		.51	.81	.58			
MIXED CLAY	33.26	25.65	12.06	4.43			
MARCASITE	2.72	1.55	4.81	12.34	17.23		
GYPSUM	1.29	1.83		.52	.51		
ROZENITE							
ALBITE							

SAMPLE ELEMENT	24B RAW BASIS (2)	24C RAW BASIS	24D RAW BASIS	24E RAW BASIS	24F RAW BASIS
LI PPM H A	66.00	59.00	33.00	36.00	25.00
BE PPM H A	3.50	2.80	3.50	2.50	1.70
B PPM L E	67.00	68.00	65.00	57.00	57.00
F PPM R O	480.00	460.00	430.00	450.00	232.00
NA PCT H A	.10	.09	.10	.06	.04
MG PCT H A	.34	.30	.29	.18	.12
AL PCT H A	5.92	5.47	5.26	4.12	3.17
SI PCT R O	17.10	14.60	15.90	9.70	8.90
P PPM R O	600.00	210.00	480.00	200.00	-10.00
CL PPM R N	37.00	39.00	31.00	55.00	40.00
K PCT H A	1.48	1.22	1.40	.97	.71
CA PCT H A	.18	.12	.16	.06	.09
SC PPM R N	18.00	15.00	12.00	10.00	6.80
TI PCT R N	.45	.41	.42	.26	.21
V PPM R N	120.00	100.00	92.00	61.00	51.00
CR PPM H A	84.00	74.00	71.00	64.00	35.60
MN PPM H A	166.50	134.00	128.50	111.00	108.00
FE PCT H A	9.00	8.50	9.50	11.20	18.20
CO PPM R N	44.00	34.00	24.00	26.00	24.00
NI PPM L E	110.00	70.00	70.00	43.00	50.00
CU PPM H A	50.00	39.00	43.00	35.00	21.00
ZN PPM H A	220.00	101.00	87.00	78.00	45.00
GA PPM R N					
GE PPM L E	-9.00	-8.00	-8.00	-7.00	-8.00
AS PPM R N	64.00	64.00	54.00	88.00	200.00
SE PPM R N	5.70	5.70	6.00	6.60	7.40
BR PPM R N				3.30	1.30
RB PPM R N	210.00	160.00	120.00	80.00	190.00
Y PPM L E	20.00	20.00	19.00	12.00	10.00
ZR PPM L E	100.00	84.00	79.00	63.00	65.00
MO PPM L E	46.00	40.00	42.00	53.00	87.00
AG PPM R N	.80	.40	.60	.70	.40
CD PPM H A	50	.20	.24	.30	.50
SN PPM L E	-9.00	-8.00	-8.00	-7.00	-8.00
SB PPM R N	1.70	1.10	1.10	1.20	1.10
CS PPM R N	9.10	7.70	5.90	4.90	2.70
LA PPM R N	50.00	45.00	35.00	25.00	24.00
CE PPM R N	110.00	91.00	70.00	55.00	50.00
SM PPM R N	8.70	7.40	5.70	4.50	4.30
EU PPM R N	1.80	1.50	1.20	.96	1.00
TB PPM R N					
DY PPM R N	6.70	5.40	5.40	3.20	3.30
YB PPM R N	3.90	3.60	3.10	2.30	2.10
LU PPM R N	.56	.51	.38	.33	.20
HF PPM R N	4.70	3.70	3.20	3.20	2.20
TA PPM R N	1.20	.98	.90		
W PPM R N				1.40	1.40
HG PPM R N					
PB PPM H A	39.00	30.00	38.00	25.00	35.00
TH PPM R O	14.00	12.00	9.60	7.80	5.10
U PPM R O	3.70	3.20	3.10	2.00	1.60

TRACE ELEMENT AND MINERAL CONTENT OF SIZED WASTE MATERIALS

FOR ILLINOIS BASIN PLANT C SAMPLES

SAMPLE	18B	18C	18D	18E	18F
IDENTITY (1)	-1/4	-1	-1D	-2	+2
LOCALE	PLANT C	PLANT C	PLANT C	PLANT C	PLANT C
DATE OBTND	11/20/75	11/20/75	11/20/75	11/20/75	11/20/75
PCT H2O					
PCT LTA					
PCT HTA	79.60	79.80	76.30	77.90	82.10
PCT ORIGNL SIZE, KG	5.50	14.00	11.50	16.00	53.00
CHNS ANAL	RAW BASIS	RAW BASIS	RAW BASIS	RAW BASIS	RAW BASIS
CARBON	8.50	6.90	7.50	7.60	9.40
HYDROGEN	1.04	.81	.98	1.20	1.32
NITROGEN	.25	.20	.26	.17	.22
SULFUR	7.65	13.70	19.17	14.11	10.72
MINERALOGY	RAW BASIS	RAW BASIS	RAW BASIS	RAW BASIS	RAW BASIS
KAOLINITE	10.61	12.98	10.77	12.23	15.89
ILLITE	18.29	21.78	12.14	18.12	13.24
QUARTZ	24.92	25.84	18.22	23.08	23.89
PYRITE	16.07	21.75	32.92	22.57	18.11
SPHALERITE					
CALCITE					
MIXED CLAY	16.12	8.05	6.00	7.43	16.49
MARCASITE			11.04	6.60	1.51
GYPSUM	3.89	2.71	1.10	.94	
ROZENITE					
ALBITE					

SAMPLE ELEMENT	18B RAW BASIS	18C RAW BASIS	18D RAW BASIS	18E RAW BASIS	18F RAW BASIS
(2)					
LI PPM H A	12.00	9.00	4.00	11.00	25.00
BE PPM H A					
B PPM L E	93.00	74.00	58.00	63.00	76.00
F PPM R O	1040.00	950.00	1550.00	1130.00	1510.00
NA PCT H A	.36	.29	.24	.29	.29
MG PCT H A	.50	.42	.29	.30	.24
AL PCT H A	7.60	7.00	6.10	7.20	7.80
SI PCT R O	17.47	16.74	13.88	15.83	17.11
P PPM R O	2400.00	2400.00	6600.00	4600.00	7500.00
CL PPM R N	115.00	90.00	76.00	57.00	170.00
K PCT H A	1.97	1.69	1.24	1.37	1.16
CA PCT H A	.84	.61	1.52	1.24	1.70
SC PPM R N	14.10	13.40	9.20	10.40	10.00
TI PCT R N	.52	.48	.38	.54	.57
V PPM R N	85.00	77.00	60.00	73.00	67.00
CR PPM H A	81.00	78.00	70.00	70.00	73.00
MN PPM H A	131.00	128.00	128.50	139.50	114.50
FE PCT H A	7.60	11.60	16.20	12.10	9.40
CO PPM R N	21.00	25.00	20.00	29.00	29.00
NI PPM L E	52.00	53.00	48.00	59.00	65.00
CU PPM H A	44.00	61.00	40.00	39.00	38.00
ZN PPM H A	149.00	86.00	99.00	79.00	74.00
GA PPM R N	22.00	16.00	15.00	15.00	17.00
GE PPM L E	4.00	6.60	6.80	-3.00	6.60
AS PPM R N	15.00	19.00	25.00	22.00	24.00
SE PPM R N	3.80	7.70	8.60	5.60	10.00
BR PPM R N			1.00		
RB PPM R N	290.00	360.00	160.00	260.00	160.00
Y PPM L E	37.00	24.00	25.00	27.00	34.00
ZR PPM L E	180.00	130.00	130.00	130.00	120.00
MO PPM L E	11.00	16.00	21.00	14.00	14.00
AG PPM R N					
CD PPM H A	.80	.35	.70	.70	1.10
SN PPM L E	-9.00	-9.00	-9.00	-9.00	-9.00
SB PPM R N	1.30	.90	1.10	1.00	1.10
CS PPM R N	9.60	10.30	4.50	6.00	6.60
LA PPM R N	49.00	49.00	39.00	48.00	52.00
CE PPM R N	93.00	95.00	95.00	85.00	95.00
SM PPM R N	7.70	7.20	5.90	6.50	7.30
EU PPM R N	1.30	1.60	1,10	1.20	1.30
TB PPM R N					
DY PPM R N	5.90	5.20	5.20	5.70	5.70
YB PPM R N	4.60	3.80	2.40	1.70	3.70
LU PPM R N	.50	.50	.30	.40	.40
HF PPM R N	4.30	4.90	2.10	4.10	3.90
TA PPM R N					1.00
W PPM R N					
HG PPM R N					
PB PPM H A	52.00	68.00	46.00	68.00	46.00
TH PPM R O	12.80	12.60	9.60	11.50	13.10
U PPM R O	5.10	5.30	10.60	8.80	11.70

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FOOTNOTES
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(1) PLUS OR MINUS INDICATES SIZE GREATER OR LESS THAN SIZE GIVEN.
    NUMBERS 6 OR LARGER ARE MESH SIZES, OTHERS ARE IN INCHES
(2) LETTERS INDICATE HOW SAMPLE WAS PREPARED AND ANALYZED
     R= RAW SAMPLE
     L= LOW TEMPERATURE ASH
     H= HIGH TEMPERATURE ASH
     N= NEUTRON ACTIVATION ANALYSIS
     A= ATOMIC ABSORPTION
     E= EMISSION SPECTROSCOPY
     O= OTHER
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APPENDIX D

SUMMARY OF LASL FLOAT/SINK ANALYSES (1)

9-30-77

LOCALE	IDENTITY (2)		SAMPLE	LTA	CHN ANAL	MINE-RALOGY	TRACE ELEMENTS
PLANT A	GOB A,C,E AVE(#25A)		F/S 10	NA	NA	NA	YES
A	FLOAT @ 2.15g/ml		F/S 10F	NA	NA	NA	YES
A	FLOAT @ 2.48	SINK @ 2.15	F/S 10E	NA	NA	NA	YES
A	FLOAT @ 2.97	SINK @ 2.48	F/S 10C	NA	NA	NA	YES
A		SINK @ 2.97	F/S 10A	NA	NA	NA	YES
PLANT B	GOB A,B,C AVE(#24A)		F/Y 13	NA	NA	NA	YES
B	FLOAT @ 2.15g/ml		F/Y 13F	YES	NA	YES	YES
B	FLOAT @ 2.48	SINK @ 2.15	F/S 13E	YES	NA	YES	YES
B	FLOAT @ 2.97	SINK @ 2.48	F/S 13C	YES	NA	YES	YES
B		SINK @ 2.97	F/S 13A	YES	NA	YES	YES
B	GOB A,B,C -1/4"(#24B)		F/S 3	NA	NA	NA	YES
B	FLOAT @ 2.15g/ml		F/S 3F	NA	NA	NA	YES
B	FLOAT @ 2.48	SINK @ 2.15	F/S 3E	NA	NA	NA	YES
B	FLOAT @ 2.97	SINK @ 2.48	F/S 3C	NA	NA	NA	YES
B		SINK @ 2.97	F/S 3A	NA	NA	NA	YES
B	GOB A,B,C +2"(#24F)		F/S 4	NA	NA	NA	YES
B	FLOAT @ 2.15g/ml		F/S 4FF	NA	NA	NA	YES
B	SUSPENDED @ 2.15		F/S 4FS	NA	NA	NA	YES
B	FLOAT @ 2.48	SINK @ 2.15	F/S 4E	NA	NA	NA	YES
B	FLOAT @ 2.97	SINK @ 2.48	F/S 4C	NA	NA	NA	YES
B		SINK @ 2.97	F/S 4A	NA	NA	NA	YES
B	LTA-GOB A,B,C AVE(#24)		F/S 16	NA	NA	NA	YES
B	FLOAT @ 2.48g/ml		F/S 16D	NA	NA	NA	YES
B	FLOAT @ 2.97	SINK @ 2.48	F/S 16C	NA	NA	NA	YES
B		SINK @ 2.97	F/S 16A	NA	NA	NA	YES
PLANT C	GOB A,B,C AVE(#18A)		F/S 11	NA	NA	NA	YES
C	FLOAT @ 2.15g/ml		F/S 11F	NA	NA	NA	YES
C	FLOAT @ 2.48	SINK @ 2.15	F/S 11E	NA	NA	NA	YES
C	FLOAT @ 2.97	SINK @ 2.48	F/S 11C	NA	NA	NA	YES
C		SINK @ 2.97	F/S 11A	NA	NA	NA	YES

TOTAL NUMBER OF SAMPLES = 24

FOOTNOTES

(1) YES=ANALYSIS DONE, NA=NO ANALYSIS IS TO BE DONE

(2) DESIGNATIONS A,B,C, ETC INDICATE THE ORDER IN WHICH SAMPLES WERE COLLECTED: A, FIRST; B, SECOND; ETC. Y=AGE OF MATERIALS IN YEARS

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                     TRACE ELEMENT AND MINERAL CONTENT OF FLOAT-SINK FRACTIONS

                          OF ILLINOIS-BASIN PLANT A COAL WASTE SAMPLES

 SAMPLE       F10A         F10C         F10E         F10F
--------   ----------   ----------   ----------   ----------   ----------   ----------   ----------
      (1)
IDENTITY    25A SK/TBE   25A SK/DBM   25A SK/DBE   25A F/DBE
LOCALE      PLANT A      PLANT A      PLANT A      PLANT A
DATE OBTND
PCT H2O
PCT LTA
PCT HTA
PCT ORIGNL     18.90        23.80        44.10        13.20
SIZE,KG

 CHNS ANAL
---------   RAW BASIS    RAW BASIS    RAW BASIS    RAW BASIS

CARBON
HYDROGEN
NITROGEN
SULFUR         36.80         2.32         4.75         2.87

 MINERALOGY
 ----------

KAOLINITE
ILLITE
QUARTZ
PYRITE
SPHALERITE
CALCITE
MIXED CLAY
MARCASITE
GYPSUM
ROZENITE
ALBITE
```

SAMPLE	F10A	F10C	F10E	F10F
ELEMENT (2)	RAW BASIS	RAW BASIS	RAW BASIS	RAW BASIS
LI PPM H A	17.00	108.00	151.00	62.00
BE PPM H A	2.00	5.00	31.00	35.00
B PPM L E	59.00	68.00	66.00	40.00
F PPM R O	1000.00	570.00	540.00	150.00
NA PCT H A	.03	.12	.10	.03
MG PCT H A	.10	.64	.54	.16
AL PCT H A	1.39	8.70	8.20	2.81
SI PCT R O	2.20	17.30	15.90	2.30
P PPM R O	6000.00	1060.00	1050.00	120.00
CL PPM R N		716.00	104.00	
K PCT H A	.16	1.46	1.34	.48
CA PCT H A	3.40	6.73	3.86	.21
SC PPM R N		11.80	12.20	6.45
TI PCT R N		.38	.46	
V PPM R N		63.80	72.10	55.80
CR PPM H A	15.00	86.00	65.00	40.00
MN PPM H A	207.00	414.00	276.00	39.30
FE PCT H A	36.00	3.14	5.10	2.00
CO PPM R N		26.50	34.70	41.10
NI PPM L E	54.00	48.00	49.00	28.00
CU PPM H A	220.00	63.00	68.00	50.00
ZN PPM H A	215.00	65.00	98.00	74.00
GA PPM R N				
GE PPM L E	-10.00	-10.00	-9.00	-4.00
AS PPM R N				
SE PPM R N				
BR PPM R N				
RB PPM R N		46.20	129.00	
Y PPM L E	23.00	32.00	35.00	17.00
ZR PPM L E	140.00	140.00	170.00	63.00
MO PPM L E	30.00	30.00	27.00	14.00
AG PPM R N				
CD PPM H A	2.60	.12	.23	.12
SN PPM L E	200.00	-10.00	-9.00	-4.00
SB PPM R N				
CS PPM R N		3.94	8.04	
LA PPM R N		41.60	44.80	40.40
CE PPM R N		79.10	92.20	53.40
SM PPM R N		4.59	5.63	2.53
EU PPM R N		1.36	1.60	
TB PPM R N		1.10		
DY PPM R N		5.21	5.57	
YB PPM R N		1 04	3.14	
LU PPM R N		.41	.48	
HF PPM R N		2 34	2.57	
TA PPM R N				
W PPM R N				
HG PPM R N				
PB PPM H A	220.00	330.00	79.00	37.00
TH PPM R O		11.30	13.80	5.90
U PPM R O		6.20	6.34	4.95

TRACE ELEMENT AND MINERAL CONTENT OF FLOAT-SINK FRACTIONS

OF ILLINOIS-BASIN PLANT B COAL WASTE SAMPLES

SAMPLE	F13A	F13C	F13E	F13F	F16A	F16C	F16D
IDENTITY (1)	24A SK/TBE	24A SK/DBM	24A SK/DBE	24A F/DBE	24ALTASKTB	24ALTASKBM	24ALTA/FBM
LOCALE	PLANT B	PLANT B	PLANT B	PLANT B	PLANT B	PLANT B	PLANT B
DATE OBTND							
PCT H2O							
PCT LTA							
PCT HTA							
PCT ORIGNL SIZE, KG	30.00	21.60	32.20	16.20	26.40	72.70	.90
CHNS ANAL	RAW BASIS	RAW BASIS	RAW BASIS	RAW BASIS			
CARBON							
HYDROGEN							
NITROGEN							
SULFUR	37.30	7.38	4.91	4.19			
MINERALOGY	RAW BASIS	RAW BASIS	RAW BASIS	RAW BASIS			
KAOLINITE	4.20	10.64	10.05	8.90			
ILLITE	11.30	24.27	19.64	10.92			
QUARTZ	2.59	32.87	22.74	12.00			
PYRITE	65.11	14.25	9.01	8.67			
SPHALERITE							
CALCITE	.95	.25					
MIXED CLAY		2.34	15.18	5.65			
MARCASITE	10.82		5.03	2.12			
GYPSUM			3.16				
ROZENITE							
ALBITE							

SAMPLE	F13A	F13C	F13E	F13F	F16A	F16C	F16D
ELEMENT (2)	RAW BASIS	RAW BASIS	RAW BASIS	RAW BASIS	RAW BASIS	RAW BASIS	RAW BASIS
LI PPM H A	19.00	112.00	206.00	79.00			
BE PPM H A	13.00	14.00	17.00	12.00			
B PPM L E	59.00	66.00	73.00	130.00			
F PPM R O	20.00	420.00	430.00	150.00			
NA PCT H A	.02	.09	.09	.03	.06	.10	.05
MG PCT H A	.06	.43	.42	.16			
AL PCT H A	1.43	9.00	8.80	3.60			
SI PCT R O	2.10	18.90	16.30	6.40			
P PPM R O	180.00	770.00	460.00	180.00			
CL PPM R N	30.30	280.00	50.00	78.90	60.60	190.00	180.00
K PCT H A	.20	1.90	1.78	.68			
CA PCT H A	.13	.11	.29	.07	.06	.13	
SC PPM R N	1.98	14.30	14.90	6.17	8.56	14.90	11.30
TI PCT R N	.07	.22	.49		.27	.42	.37
V PPM R N	11.70	79.10	73.70	35.20	57.70	110.00	73.00
CR PPM H A	9.50	83.00	76.00	40.00			
MN PPM H A	205.50	133.00	96.75	36.10	189.00	147.00	58.00
FE PCT H A	36.10	8.70	5.70	3.30			
CO PPM R N	28.50	37.10	40.90	38.50	32.10	38.70	36.00
NI PPM L E	77.00	74.00	62.00	29.00			
CU PPM H A	95.00	68.00	42.00	20.00			
ZN PPM H A	123.00	110.00	104.00	42.00			
GA PPM R N		150.00					
GE PPM L E	-10.00	-10.00	-9.00	-6.00			
AS PPM R N	202.00				134.00	57.70	
SE PPM R N							
BR PPM R N							
RB PPM R N		197.00		134.00		172.00	
Y PPM L E	13.00	27.00	31.00	16.00			
ZR PPM L E	140.00	160.00	150.00	67.00			
MO PPM L E	13.00	21.00	20.00	13.00			
AG PPM R N							
CD PPM H A	.80	.25	.12	.06			
SN PPM L E	-10.00	-10.00	-9.00	-6.00			
SB PPM R N	1.67				.08		
CS PPM R N		5 99	9.13	2.43	3.38	7.05	5.11
LA PPM R N	3.73	42.60	27.50		24.10	38.80	22.10
CE PPM R N		87.90	92.00	36.20	49.80	88.70	74.80
SM PPM R N	.39	5.00	3.70	2.43	2.46	4.18	2.23
EU PPM R N	21.60	1.97	1.22	.57	.81	1.22	
TB PPM R N		1.56					
DY PPM R N		4.70	5.52		2.44	5.44	2.78
YB PPM R N		2.45			1.22	3.26	
LU PPM R N	.23	.32	.31		.20	.51	.34
HF PPM R N	2.65	2.69			3.79	5.73	
TA PPM R N		.95				1.89	
W PPM R N							
HG PPM R N							
PB PPM H A	48.00	32.00	32.00	10.00			
TH PPM R O	2.16	12.20	14.70	4.38	6.24	9.75	6.29
U PPM R O	.54	3.98	3.72	1.76	2.38	4.07	2.66

TRACE ELEMENT AND MINERAL CONTENT OF FLOAT-SINK FRACTIONS

OF ILLINOIS-BASIN PLANT B COAL WASTE SAMPLES

SAMPLE	F 3A	F 3C	F 3E	F 3F	F 4A	F 4C	F 4E
(1)							
IDENTITY	24B SK/TBE	24B SK/DBM	24B SK/DBE	24B F/DBE	24F SK/TBE	24F SK/DBM	24F SK/DBE
LOCALE	PLANT B	PLANT B	PLANT B	PLANT B	PLANT B	PLANT B	PLANT B
DATE OBTND							
PCT H2O							
PCT LTA							
PCT HTA							
PCT ORIGNL	5.40	37.70	51.30	5.70	40.20	25.60	5.20
SIZE, KG							
CHNS ANAL	RAW BASIS	RAW BASIS	RAW BASIS	RAW BASIS	RAW BASIS	RAW BASIS	RAW BASIS
CARBON							
HYDROGEN							
NITROGEN							
SULFUR	39.70	8.26	4.66	2.90	42.50	12.30	8.40
MINERALOGY							
KAOLINITE							
ILLITE							
QUARTZ							
PYRITE							
SPHALERITE							
CALCITE							
MIXED CLAY							
MARCASITE							
GYPSUM							
ROZENITE							
ALBITE							

SAMPLE	F 3A	F 3C	F 3E	F 3F	F 4A	F 4C	F 4E
ELEMENT (2)	RAW BASIS	RAW BASIS	RAW BASIS	RAW BASIS	RAW BASIS	RAW BASIS	RAW BASIS
LI PPM H A	31.00	141.00	169.00	124.00	16.00	89.00	178.00
BE PPM H A	6.00	33.00	10.00	11.00	6.00	6.00	25.00
B PPM L E	41.00	57.00	75.00	53.00	57.00	59.00	66.00
F PPM R O	50.00	350.00	380.00		70.00	370.00	360.00
NA PCT H A	.02	.10	.10	.05	.01	.07	.08
MG PCT H A	.08	.46	.43	.23	.03	.03	.30
AL PCT H A	2.38	9.70	9.10	4.85	.73	6.30	6.60
SI PCT R O	3.80	18.10	16.40	8.80	1.90	18.00	11.60
P PPM R O	240.00	560.00	500.00	250.00	90.00	770.00	540.00
CL PPM R N	61.30	139.00	251.00	197.00	28.70	465.00	1020.00
K PCT H A	.32	1.99	1.84	.94	.16	1.45	1.26
CA PCT H A	.11	.40	.27	.09	.09	.23	.30
SC PPM R N	3.30	15.00	13.70	8.57	1.75	14.40	11.00
TI PCT R N	.09	.41	.56	.06		.30	.23
V PPM R N	21.20	112.00	101.00	53.90	4.98	66.60	
CR PPM H A	20.00	79.00	77.00	52.00	16.00	61.00	61.00
MN PPM H A	350.50	200.00	130.00	51.35	89.50	136.50	103.90
FE PCT H A	35.10	8.50	5.40	2.70	35.50	12.50	9.70
CO PPM R N	51.40	43.20	46.40	41.00	30.10	48.30	50.70
NI PPM L E	140.00	100.00	86.00	37.00	39.00	66.00	63.00
CU PPM H A	116.00	67.00	48 00	35.00	29.00	33.00	33.00
ZN PPM H A	430.00	198.00	150.00	72.00	21.00	82.00	77.00
GA PPM R N	19.80						
GE PPM L E	-10.00	-9.00	-8.00	-7.00	-10.00	-10.00	-9.00
AS PPM R N	214.00					70.90	
SE PPM R N							
BR PPM R N							
RB PPM R N		296.00	73.60			118.00	92.60
Y PPM L E	14.00	35.00	33.00	21.00	11.00	26.00	27.00
ZR PPM L E	120.00	220.00	150.00	110.00	140.00	140.00	120.00
MO PPM L E	24.00	23.00	22.00	20.00	19.00	35.00	41.00
AG PPM R N	.27						
CD PPM H A	1.60	.39	.30	.19	.25	.17	.50
SN PPM L E	-10.00	-9.00	-8.00	-7.00	-10.00	-10.00	-9.00
SB PPM R N	1.80						
CS PPM R N		4.69	8.53	3.65		3.53	4.25
LA PPM R N	6.78	47.90	43.80	25.10	2.79	65.60	40.90
CE PPM R N		94.30	73 10	31.40		122.00	46.00
SM PPM R N	1.09	5.82	3.19	3.45	.37	7.77	5.75
EU PPM R N	.30	2.07	1.29			2.08	1.84
TB PPM R N			1.18				
DY PPM R N	1.18	6.39	4.95			5.06	6.08
YB PPM R N			2.76				
LU PPM R N	.28	.32	.53				
HF PPM R N	1.84				.47	3.32	
TA PPM R N							
W PPM R N							
HG PPM R N	1.59				5.41		
PB PPM H A	25.00	37.00	52.00	29.00	65.00	69.00	60.00
TH PPM R O	2.93	13.40	11.30	6.20	1.33	11.70	7.96
U PPM R O	.89	4.21	4.11	2.47	.55	2.93	3.02

TRACE ELEMENT AND MINERAL CONTENT OF FLOAT-SINK FRACTIONS

OF ILLINOIS-BASIN PLANT B COAL WASTE SAMPLES

SAMPLE	F4FS	F4FF					
(1)							
IDENTITY	24F F/DBE	24F F/DBE					
LOCALE	PLANT B	PLANT B					
DATE OBTND							
PCT H2O							
PCT LTA							
PCT HTA							
PCT ORIGNL	5.10	23.90					
SIZE,KG							
CHNS ANAL	RAW BASIS	RAW BASIS					
CARBON							
HYDROGEN							
NITROGEN							
SULFUR	5.28	5.80					
MINERALOGY							
KAOLINITE							
ILLITE							
QUARTZ							
PYRITE							
SPHALERITE							
CALCITE							
MIXED CLAY							
MARCASITE							
GYPSUM							
ROZENITE							
ALBITE							

```
 SAMPLE            F4FS          F4FF
--------        ----------    ----------    ----------    ----------    ----------    ----------    ----------
ELEMENT         RAW BASIS     RAW BASIS
             (2)
 LI PPM H A        61.00         60.00
 BE PPM H A        11.00         12.00
 B  PPM L E        56.00         58.00
 F  PPM R O        80.00        110.00
 NA PCT H A          .04           .02
 MG PCT H A          .17           .10
 AL PCT H A         3.50          2.18
 SI PCT R O         4.90          2.10
 P  PPM R O       390.00        250.00
 CL PPM R N       785.00         94.20
 K  PCT H A          .74           .42
 CA PCT H A          .09           .09
 SC PPM R N         6.98          4.45
 TI PCT R N          .32
 V  PPM R N        46.80
 CR PPM H A        47.00         30.00
 MN PPM H A        74.95         33.15
 FE PCT H A         5.40          4.50
 CO PPM R N        49.70         72.40
 NI PPM L E        36.00         26.00
 CU PPM H A        24.00         16.00
 ZN PPM H A        74.00         24.00
 GA PPM R N
 GE PPM L E        -4.00         -6.00
 AS PPM R N
 SE PPM R N
 BR PPM R N
 RB PPM R N       233.00
 Y  PPM L E        16.00         14.00
 ZR PPM L E        74.00         47.00
 MO PPM L E        26.00          7.20
 AG PPM R N
 CD PPM H A          .16           .10
 SN PPM L E        -4.00         -6.00
 SB PPM R N
 CS PPM R N         2.61
 LA PPM R N        25.30         25.30
 CE PPM R N        41.50         41.50
 SM PPM R N         3.42
 EU PPM R N
 TB PPM R N          .74
 DY PPM R N
 YB PPM R N
 LU PPM R N
 HF PPM R N
 TA PPM R N
 W  PPM R N
 HG PPM R N
 PB PPM H A        57.00         25.00
 TH PPM R O         5.89          3.75
 U  PPM R O         2.01          1.20
```

TRACE ELEMENT AND MINERAL CONTENT OF FLOAT-SINK FRACTIONS

OF ILLINOIS-BASIN PLANT C COAL WASTE SAMPLES

SAMPLE	F11A	F11C	F11E	F11F
IDENTITY (1)	18A SK/TBE	18A SK/DBM	18A SK/DBE	18A F/DBE
LOCALE	PLANT C	PLANT C	PLANT C	PLANT C
DATE OBTND				
PCT H2O				
PCT LTA				
PCT HTA				
PCT ORIGNL	17.60	65.80	8.40	8.20
SIZE, KG				
CHNS ANAL	RAW BASIS	RAW BASIS	RAW BASIS	RAW BASIS
CARBON				
HYDROGEN				
NITROGEN				
SULFUR	33.60	3.90	4.17	4.40
MINERALOGY				
KAOLINITE				
ILLITE				
QUARTZ				
PYRITE				
SPHALERITE				
CALCITE				
MIXED CLAY				
MARCASITE				
GYPSUM				
ROZENITE				
ALBITE				

SAMPLE	F11A	F11C	F11E	F11F
ELEMENT (2)	RAW BASIS	RAW BASIS	RAW BASIS	RAW BASIS
LI PPM H A	86.00	79.00	140.00	28.00
BE PPM H A	-1.00	16.00	32.00	15.00
B PPM L E	80.00	99.00	100.00	26.00
F PPM R O	470.00	1300.00	1100.00	160.00
NA PCT H A	.08	.37	.34	.07
MG PCT H A	.06	.39	.46	.10
AL PCT H A	1.64	9.70	8.90	2.32
SI PCT R O	3.50	19.40	19.80	2.10
P PPM R O	9260.00	4020.00	2410.00	450.00
CL PPM R N	121.00	256.00	171.00	214.00
K PCT H A	.23	1.77	1.99	.35
CA PCT H A	2.73	1.20	.90	.23
SC PPM R N	2.54	12.40	12.30	3.58
TI PCT R N	.12	.54	.50	
V PPM R N	10.00	73.90	73.90	25.00
CR PPM H A	18.00	116.00	147.00	76.00
MN PPM H A	98.20	120.00	118.00	32.70
FE PCT H A	34.50	4.60	4.50	2.60
CO PPM R N	29.10	30.30	29.60	40.30
NI PPM L E	60.00	51.00	60.00	31.00
CU PPM H A	191.00	124.00	86.00	28.00
ZN PPM H A	475.00	88.00	116.00	28.00
GA PPM R N			60.20	
GE PPM L E	-10.00	-10.00	-10.00	-3.00
AS PPM R N				
SE PPM R N				
BR PPM R N				
RB PPM R N		128.00	141.00	
Y PPM L E	31.00	31.00	34.00	10.00
ZR PPM L E	120.00	110.00	140.00	55.00
MO PPM L E	26.00	25.00	27.00	15 00
AG PPM R N				
CD PPM H A	6.60	.35	.88	1.80
SN PPM L E	79.00	-10.00	-10.00	-3.00
SB PPM R N	2.59		2.80	
CS PPM R N		7.30	8.21	2.93
LA PPM R N	25.70	49.30	38.80	
CE PPM R N	35.00	92.00	87.40	35.60
SM PPM R N	2.53	5.28	5.29	1.35
EU PPM R N	.70	2.46	1.35	.69
TB PPM R N				
DY PPM R N	2.36	5.06	4.94	1.20
YB PPM R N	.82	3.60	2.09	
LU PPM R N	.22	.42	.54	
HF PPM R N		2.87	4.22	
TA PPM R N		1.13	1.03	
W PPM R N				
HG PPM R N				
PB PPM H A	320.00	52.00	30.00	42.00
TH PPM R O	3.41	13.60	12.40	5.31
U PPM R O	18.50	11.21	8.27	2.70

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FOOTNOTES
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(1) PLUS OR MINUS INDICATES SIZE GREATER OR LESS THAN SIZE GIVEN.
    NUMBERS 6 OR LARGER ARE MESH SIZES, OTHERS ARE IN INCHES
(2) LETTERS INDICATE HOW SAMPLE WAS PREPARED AND ANALYZED
     R= RAW SAMPLE
     L= LOW TEMPERATURE ASH
     H= HIGH TEMPERATURE ASH
     N= NEUTRON ACTIVATION ANALYSIS
     A= ATOMIC ABSORPTION
     E= EMISSION SPECTROSCOPY
     O= OTHER
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APPENDIX E

GRAPHIC DISPLAY OF CLUSTERED TRACE ELEMENT/MINERAL CORRELATION COEFFICIENTS FOR COAL PREPARATION WASTES FROM THREE ILLINOIS BASIN COAL CLEANING PLANTS

This appendix describes the computational and graphics methods used to convert the expansive listings of trace element and mineral data for Illinois Basin coal refuse into a form from which element-element and element-mineral associations can be recognized more easily. Included also in this appendix are the graphic results from the application of these methods to data for the as-collected coal and waste samples, and for refuse samples that had been separated into fractions on the basis of density or particle size.

As the first step of this computational routine, trace element and mineral data for the various coal and refuse fractions are evaluated by bivariate correlation analysis. The program for performing this task was the Pearson's correlation option of the statistical program called SPSS. A manual is available, titled *Statistical Package for the Social Sciences*, Second Ed., by Nie et al., published by McGraw-Hill Book Co., New York, 1975. The data from this treatment are often tabulated, with the result that extensive visual inspection is necessary to find even pairs of correlated variables. Finding groups of correlated elements and minerals is even more difficult by visual inspection. To group the trace elements and minerals into clusters or sets that have similar correlation coefficients, we have developed a method for sorting the information by means of three algorithms.

The initial sorting involves selecting variables from the original unsorted group and placing them in a sorted group. The algorithms used to accomplish this are termed maximum, minimum, and average. In each of the three algorithms, the two variables with the maximum correlation are selected and placed in the sorted group. Variables are then added one at a time to the sorted group in the following manner. At the nth step variables in the sorted group are denoted by B_1, B_2, ...B_n. The remaining variables (those not yet sorted) are denoted by A_1, A_2, ...A_{n-m}. Variables are then taken from the A group one at a time, according to the algorithm chosen. To accomplish this, a statistic Z_i $(i=1,2...n-m)$ is calculated. Letting $\rho(A,B)$ denote calculated Pearson's correlation coefficient between a variable in group A and one in group B, Z_i is defined as

$$Z = \max_{j=1,m} [\rho(A_i, B_j)]$$

for the maximum algorithm. Thus for any variable (A_i) in the unsorted group, the maximum Pearson's correlation coefficient for this variable and *any* of the variables in the sorted group (B) is given as Z_i. Similarly,

$$Z_i = \min_{j=1,m} [\rho(A_i, B_j)]$$

for the minimum algorithm. For the average algorithm,

$$Z = 1/m \sum_{j=1}^{m} \rho(A_i, B_j)$$

Here, for any variable (A_i) in the unsorted group, the average of the Pearson's correlation coefficients for this variable and *all* of the variables in the sorted group (B) is given as Z_i. This set of Z's is inspected and the maximum value

$$[Z_k = \max_{i=1,n-m}(Z_i)]$$

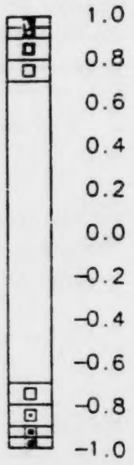
is selected. The variable A_k that corresponds to this Z-value is removed from the unsorted group (A) and placed in the sorted group (B).

The secondary sorting process takes the variable chosen from the unsorted group and places it in an orderly manner into the sorted group. The placement is either as the first member of the sorted group or as the last. To be placed as the first member, the variable must have a higher average correlation with a designated number (w) of variables in the first half of the sorted group than with a corresponding number of variables in the second half. If only the outermost variables at each end of the sorted group are to be considered, then the designated number (w) of variables is one. Considering two outermost variables, w will equal two. The choice of variables to be considered can be increased to a maximum of one-half of the number of variables in the sorted group. The placement of A_k as the first member of the sorted group is thus determined by the following condition:

$$\sum_{i=1}^{w} \rho(A_k,B_i) > \sum_{i=1}^{w} \rho(A_k,B_{m-i+1}) \quad ,$$

where w = min (m/2,w) and w is a preselected integer. If this condition is not met, then A_k is placed as the last member of the sorted group. If w = 0, A_k is always placed as the last member in the sorted group. After the last variable in the unsorted group has been added to the sorted group, the sorted group is ready for tabulation.

Because the inspection and interpretation of the voluminous number of correlation coefficients of even a sorted tabulation is still laborious, we have developed a process by which these data can be graphically displayed. This is accomplished by assigning a symbol (or a color, where facilities permit) that corresponds to a range of Pearson's correlation coefficients. Such an assignment is given at the right. Using these symbols, the relatively nondescript, but sorted, accumulation of correlation coefficients can be transformed into readily discernible groups which permit easy visual inspection. Such outputs are found in Figs. E-1 through E-11.



The computer programming used to accomplish this graphic depiction was the DISSPLA software product supplied by Integrated Software Systems Corp., San Diego, California. Hardware output has been successful with Tektronix 4000 series graphics terminals, and with Stromberg Carlson Model 4020 microfilm recorder (black and white) and Information International, Inc., Model FR80 microfilm recorder (black and white and color) 35-mm film outputs. (For investigators with only alphanumeric-type terminals, we have demonstrated that proper selection of alphanumeric characters will give a fairly discernible, but skewed, graphics output without the need for the special software or hardware units noted above. Further refinements, such as removing the skew and overstriking could greatly improve this process.)

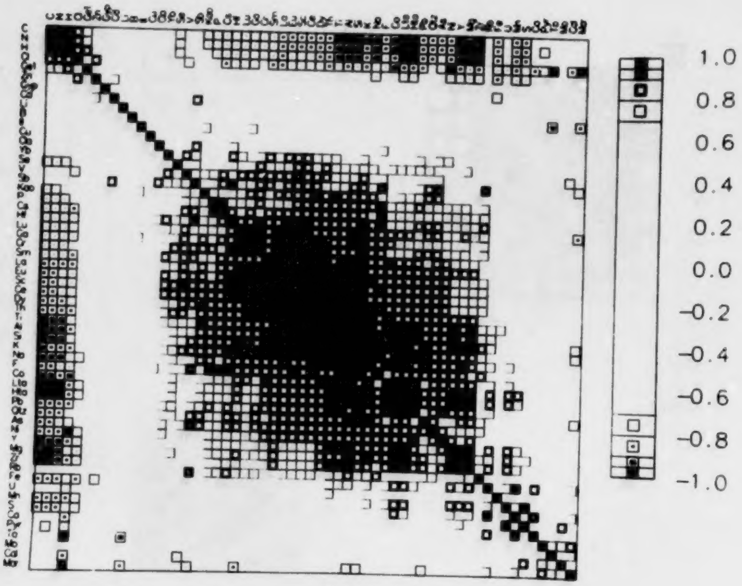


Fig. E-1.
Trace element correlation coefficients for all coal and refuse samples collected from cleaning Plant A.

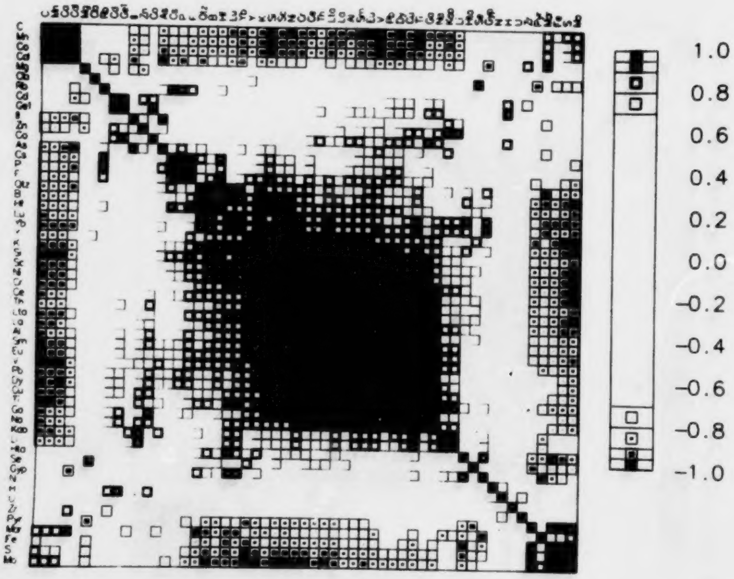


Fig. E-2.
Trace element correlation coefficients for sized refuse fractions from cleaning Plant A (samples 25b-f).

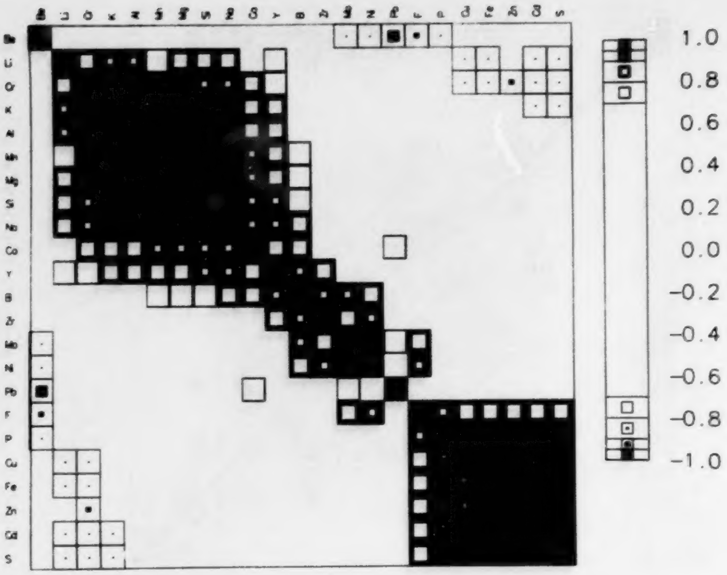


Fig. E-3.
Trace element correlation coefficients for float/sink fractions of average refuse from cleaning Plant A (sample F10).

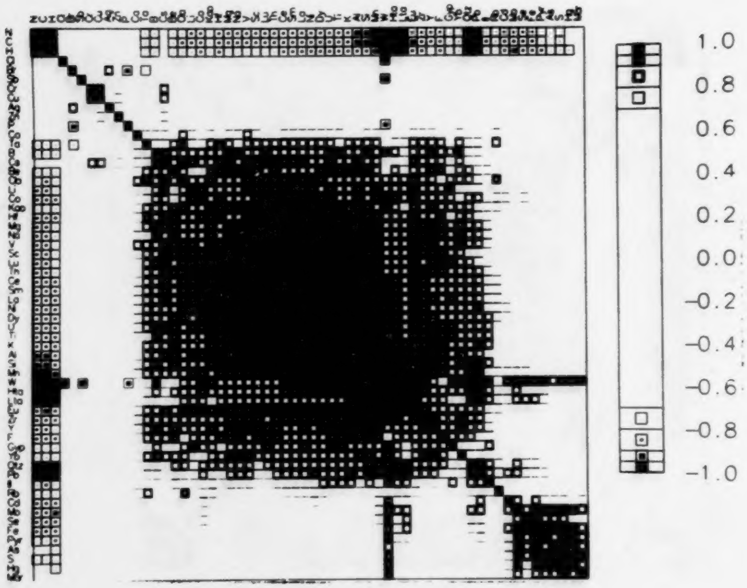


Fig. E-4.
Trace element correlation coefficients for all coal and refuse samples collected from cleaning Plant B.

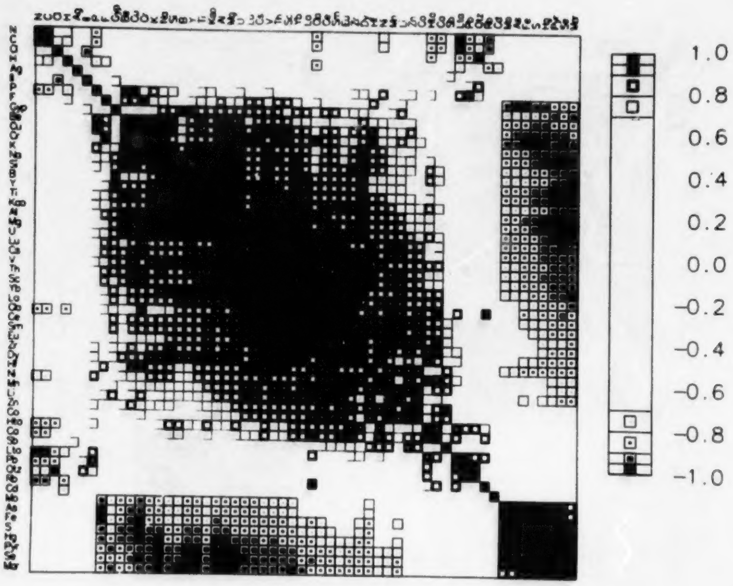


Fig. E-5.
Trace element correlation coefficients for sized refuse fractions from cleaning Plant B (samples 24b-f).

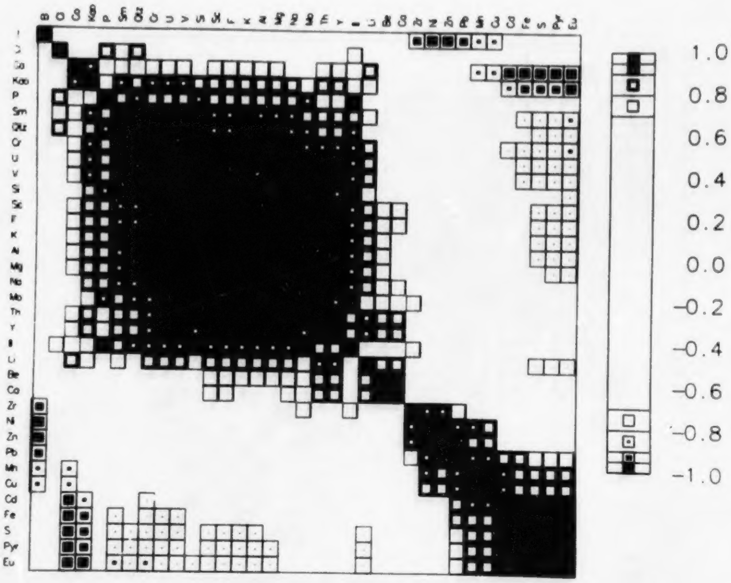


Fig. E-6.
Trace element correlation coefficients for float/sink fractions of average refuse from cleaning Plant B (sample F13).

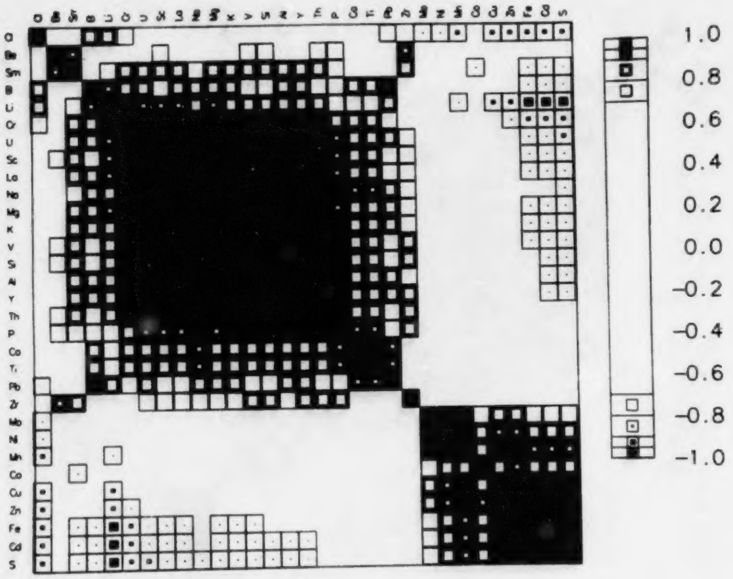


Fig. E-7.
Trace element correlation coefficients for float/sink fractions of −1/4 -in. refuse from cleaning Plant B (sample F3).

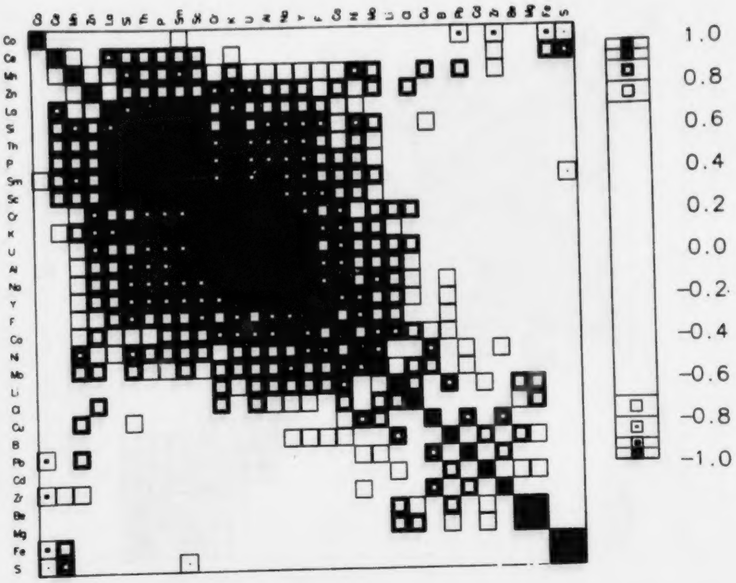


Fig. E-8.
Trace element correlation coefficients for float/sink fractions of +2-in. refuse from cleaning Plant B (sample F4).

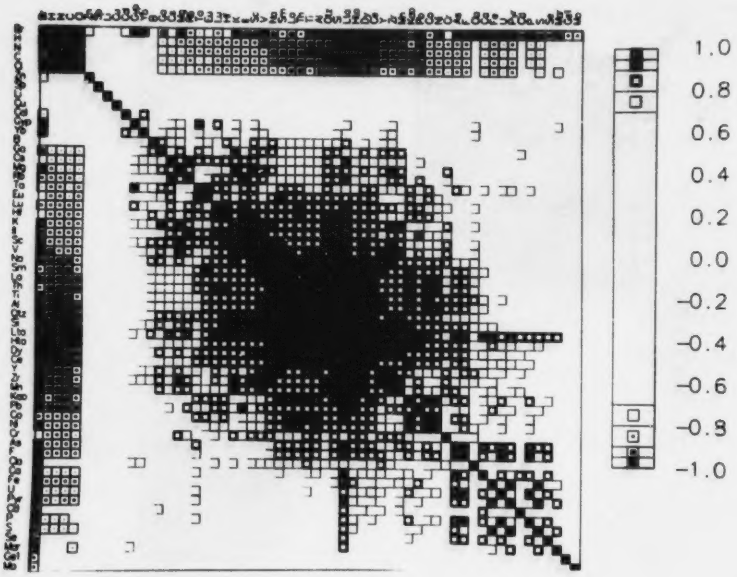


Fig. E-9.
Trace element correlation coefficients for all coal and refuse samples collected from cleaning Plant C.

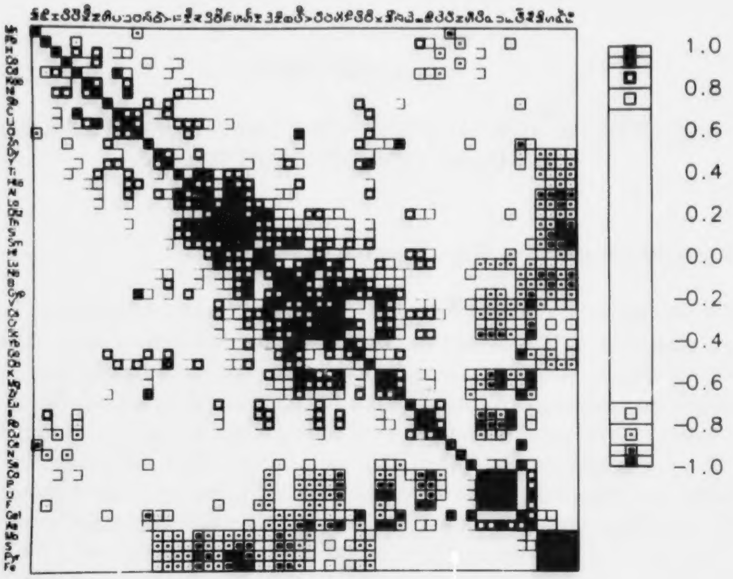


Fig. E-10.
Trace element correlation coefficients for sized refuse fractions from cleaning Plant C (sample 18b-f).

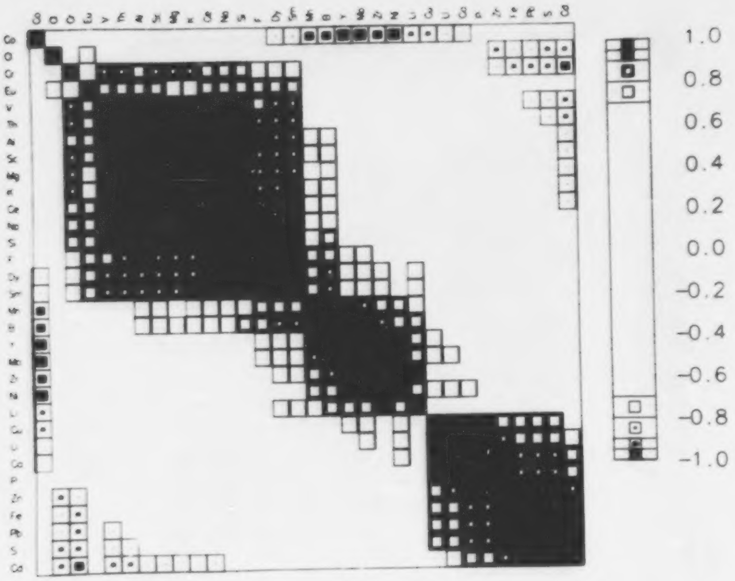


Fig. E-11.
Trace element correlation coefficients for float/sink fractions of average refuse from cleaning Plant C (sample F11).

APPENDIX F

PROCEDURE FOR MULTISTAGE FLOAT/SINK SEPARATION OF COAL PREPARATION WASTES

Step 1: Dibromomethane Float/Sink Separation

Powdered waste material (200 g of −20 mesh) was added to a 2-ℓ separatory funnel containing 1 ℓ of dibromomethane (DBM). (DBM has a density of 2.48 g/cm^3.) After shaking to promote thorough mixing, the contents were allowed to settle until the float and sink fractions were clearly separated, generally requiri[illegible] to 30 min. Then, the sink fraction was drained from the separatory funnel via the sto[illegible]k and filtered with a Buchner funnel equipped with Whitman #40 paper. The float portion, remaining in the separatory funnel, was resuspended by shaking, and the settling and separation steps were repeated. This sequence was repeated as many times as necessary to achieve the desired separation. After the removal of the last sink fraction, the remaining float material was removed from the funnel and also filtered with the Buchner apparatus. The float and sink fractions were then dried in a vacuum oven at 60°C. This operation provides two waste fractions, one with a higher density and another with a lower density than 2.48 g/cm^3.

Step 2: Dibromoethane Float/Sink Separation

The dried float portion from the DBM treatment (waste material with a density less than 2.48 g/cm^3) was transferred into another separatory funnel containing 1 ℓ of dibromoethane (DBE), which has a density of 2.15 g/cm^3. A sequence of settling and separation steps, similar to those described in Step 1, was performed. The dried products represent the waste materials that fall into the density ranges <2.15 g/cm^3 and 2.15 to 2.48 g/cm^3.

Step 3: Tetrabromoethane Float/Sink Separation

The sink fraction from the DBM treatment (density >2.5 g/cm^3) was separated into two additional density fractions by a float/sink treatment with tetrabromoethane (d=2.96 g/cm^3). The steps and work-up procedure for the products were identical to those given in Step 1. The waste fractions obtained in this step have densities in the range 2.48 to 2.97 g/cm^3 and >2.97 g/cm^3.

A flow diagram for the entire float/sink process appears in Fig. F-1.

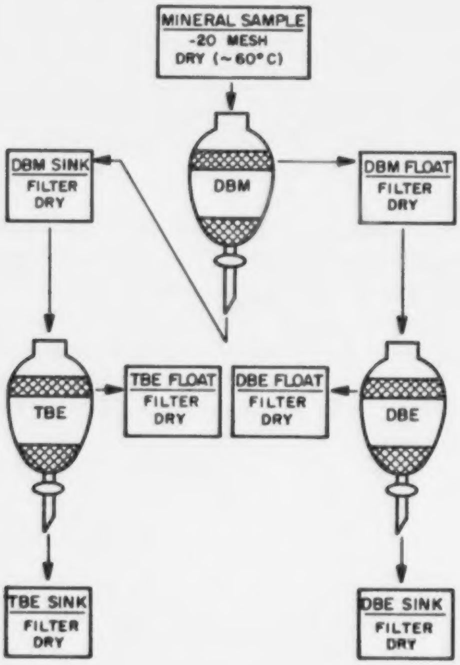

MINERAL SAMPLE
-20 MESH
DRY (~60°C)
DBM SINK
FILTER
DRY
DBM
DBM FLOAT
FILTER
DRY
TBE
TBE FLOAT
FILTER
DRY
DBE FLOAT
FILTER
DRY
DBE
TBE SINK
FILTER
DRY
DBE SINK
FILTER
DRY

Fig. F-1.
Schematic for multistage float/sink technique.

APPENDIX G

SAMPLE PREPARATION PROCEDURE FOR MICROPROBE ANALYSIS OF COAL AND REFUSE MATERIALS

After grinding the sample to the desired size (usually −20 mesh), the powder is mounted in the upper part of a 2.54-cm- (1-in.-) diam by 3.8-cm- (1.5-in.-) long cylinder of epoxy. This is accomplished by placing the powder into a small blind hole at the top of the cylinder and filling the remainder of the hole with epoxy resin. After curing the resin, the surface of the mounted specimen is ground and polished to expose the powder particles. Special care and nonaqueous polishing are needed because there is a wide range of hardnesses among the samples. Then, to improve contrast, the polished surface is etched for about 5 min, using bombardment by 3-kV H^+ ions in a cathode vacuum etcher. Finally, a 100-Å gold or carbon film is applied to the etched surface of the sample.

APPENDIX H

PROCEDURE FOR STATIC/EQUILIBRIUM LEACHING OF COAL OR WASTE MATERIALS

The crushed coal or waste sample (50 g) was added to 250 ml of leachate (distilled water or acid) contained in a 500-ml Erlenmeyer flask. The flask was either stoppered or fitted with a modified stopper that allowed air into the flask while retaining the contents. Heating, when desired, was provided by a Variac-controlled heating mantle. The completed flask assembly was inserted into a shaking apparatus that was used to agitate the sample during the experiment. After the leach period, the sample was removed from the shaker and the leachate and residue were separated by vacuum filtration. The pH, dissolved solids, and trace element contents of the leachates were then determined.

APPENDIX I

EXPERIMENTAL PROCEDURE FOR COLUMN LEACHING STUDIES OF COAL AND COAL REFUSE

Coal or refuse material (1.5 kg), crushed to −3/8 in., was packed into a Pyrex column 70 cm long by 4.6 cm diam in a vertical position. The leaching column was equipped with a necked-down inlet at the bottom for introducing the leachates. A side arm located 5 cm below the open top served as an effluent outlet. Both the upper and lower ends of the coal or refuse bed were retained in the column with loosely packed glass-wool plugs. An upward or countercurrent leachate flow was used in most of the experiments to prevent flow blockage from fine sediments that might settle to the bottom of the column.

The leachate, usually distilled water, was gravity-fed through the packed column from a reservoir elevated above the column outlet. Leachate flow rate, normally 0.5 to 1.0 ml/min, was regulated with a valve located between the reservoir and column inlet. Measurements of leachate flow and pH were made at the column outlet. Periodically, samples of leachate were collected for analysis of total solids and trace element composition.

The refuse or coal column was easily dried by stopping the leachate flow, disconnecting the inlet tubing, and draining the liquid from the sample column through the inlet. Then a dry or moist air supply was connected to the column inlet and maintained at approximately 10 scf/h.

APPENDIX J

DESCRIPTION OF STATIC LEACHING EXPERIMENTS WITH REFUSE FROM ILLINOIS BASIN CLEANING PLANTS A, B,AND C

Experiments No. GL-22, SGL-5,and GL-21

Leachate No.	Refuse Size	T, °C	Air	Time (Days)
Plant A[a] 1	-20 mesh	22	open	1
2	-20 mesh	22	open	7
3	-20 mesh	22	open	28
4	-20 mesh	22	open	56
Plant B[b] 6	-20 mesh	22	open	1
12	-20 mesh	22	open	7
18	-20 mesh	22	open	28
22	-20 mesh	22	open	56
Plant C[c] 1	-20 mesh	22	open	1
2	-20 mesh	22	open	7
3	-20 mesh	22	open	28

---

[a] An average of refuse samples 12, 25,and 28 was used in this study.

[b] An average of refuse samples 17, 23,and 24 was used in this investigation.

[c] An average refuse material consisting of sample numbers 18 through 22 was used in this study.

ANALYSES FROM STATIC LEACHING OF REFUSE FROM ILLINOIS BASIN PLANT A
EXPERIMENT No. GL-22[a]

	Leachate Sample No.			
	1	2	3	4
Time (Days)	1	7	28	56
pH	7.1	7.4	7.6	7.8
TDS[b]	0.28	0.27	0.26	0.28
Na	2.4	24	30	31
Mg	360	400	470	540
Al	1.0	1.0	0.5	< 0.2
SiO_2				
K	47	49	57	38
Ca	3000	2900	3100	2900
Sc	< 0.01	< 0.01	< 0.01	< 0.01
V	< 0.02	< 0.02	< 0.02	< 0.02
Cr(μg/kg)	< 5	< 5	6	7
Mn	22.0	10.3	8.9	9.7
Fe	< 0.1	< 0.1	0.26	< 0.1
Co	3.2	0.5	0.2	0.12
Ni	6.9	1.0	0.6	0.4
Cu	< 0.01	< 0.01	0.01	0.05
Zn	0.62	0.52	0.33	0.19
Ga	< 0.2	< 0.2	< 0.2	< 0.2
As	< 0.04	< 0.04	< 0.04	< 0.04
Br	0.06	0.07	0.03	0.07
Rb	<8	< 8	< 8	< 8
Ag	<0.04	< 0.04	< 0.04	0.06
Cd(μg/kg)	6.8	2.0	1.4	0.6
Sb	< 0.01	< 0.2	< 0.2	< 0.2
Cs	< 0.16	< 0.16	< 0.16	< 0.16
La	< 2	< 2	< 2	< 2
Ce	< 0.32	< 0.32	< 0.32	< 0.32
Sm	< 0.08	< 0.08	< 0.08	< 0.08
Eu	< 0.02	< 0.02	< 0.02	< 0.02
Tb				
Dy	< 0.01	< 0.01	< 0.01	< 0.01
Yb	< 0.12	< 0.12	< 0.12	< 0.12
Lu	< 0.01	< 0.01	< 0.01	< 0.01
Hf	< 0.08	< 0.08	< 0.08	< 0.08
Ta	< 0.2	< 0.2	< 0.2	< 0.2
W	< 0.04	< 0.04	< 0.04	< 0.04
Hg	< 1	< 1	< 1	< 0.03
Pb(μg/kg)	240	40	30	150
Th	< 0.08	< 0.08	< 0.08	< 0.08
U	< 0.01	< 0.01	< 0.01	< 0.01

---

[a] Elemental concentrations reported as μg/g of refuse unless otherwise indicated.

[b] Total dissolved solids reported as wt. %.

ANALYSES FROM STATIC LEACHING OF REFUSE
FROM ILLINOIS BASIN PLANT B

Experiment No. SGL-5[a]

	Leachate Sample No.			
	6	12	18	22
Time (days)	1	7	28	56
pH	2.2	2.0	1.8	1.7
TDS[b]	1.05	1.15	2.67	5.10
Na	12.3	9.8	3.2	2.4
Mg	269.9	251.2	261.9	266.5
Al	976	938	1070	1123
SiO_2				
K	8.4	7.0	1.3	2.4
Ca	809	759	803	809
Sc		2.0		
V	1.38	1.8	2.00	2.48
Cr (μg/kg)	780	330	850	910
Mn	31.5	32.5	39.4	47.7
Fe	9500	10000	28600	50800
Co	21.0	19.6	20.5	20.9
Ni	32.7	31.0	35.2	38.0
Cu	1.6	1.6	10.9	18.5
Zn	50.8	65.3	93.9	134.3
Ga		<0.2		
As		3.4		
Br		<0.04		
Rb		<8		
Ag		<0.04		
Cd (μg/kg)	190	260	290	310
Sb		<0.2		
Cs		<0.16		
La		1.84		
Ce		2.49		
Sm		0.58		
Eu		0.14		
Tb				
Dy	0.66	0.86	0.86	< 0.01
Yb		<0.12		
Lu		0.03		
Hf		<0.08		
Ta		<0.2		
W		0.09		
Hg		<1		
Pb	1.6	1.5	1.4	1.2
Th		0.64		
U		0.38		

---

[a] Elemental concentrations reported as μg/g of refuse unless otherwise noted.

[b] Total dissolved solids reported as wt%.

ANALYSES FROM STATIC LEACHING OF REFUSE FROM ILLINOIS BASIN PLANT C

EXPERIMENT No. GL-21[a]

	Leachate Sample No.		
	1	2	3
Time (Days)	1	7	28
pH	3.5	3.3	1.88
TDS[b]	0.31	0.33	1.81
Na	1800	1500	1500
Mg	161	186	243
Al	124	80	613
K	97	60	15
Ca	1400	2100	2800
Sc	0.12	0.11	1.19
V	0.02	<0.02	0.9
Cr(μg/kg)	160	42	1200
Mn	16.8	20.8	52.8
Fe	1800	230	14000
Co	9.4	10.5	20.3
Ni	14	18	39
Cu	0.05	0.60	11.4
Zn	6.9	10.6	39
Ga	<0.2	<0.2	<0.2
As	<0.02	<0.02	0.88
Br	0.15	<0.04	<0.04
Rb	<8	<8	<8
Ag	<0.04	<0.04	<0.04
Cd(μg/kg)	100	89	620
Sb	<0.2	<0.2	<0.2
Cs	<0.16	<0.16	<0.16
La	0.35	0.46	3.41
Ce	1.61	1.94	9.11
Sm	0.24	0.24	13.8
Eu	0.05	0.05	0.25
Dy	0.25	0.25	1.28
Yb	0.04	<0.12	0.29
Lu	0.01	0.01	0.05
Hf	<0.08	<0.08	<0.08
Ta	<0.2	<0.2	<0.2
W	<0.04	<0.04	<0.04
Hg	<1	<1	<1
Pb(μg/kg)	1600	2700	1800
Th	<0.08	0.02	1.11
U	0.20	0.13	3.37

---

[a] Elemental concentrations reported as μg/g of refuse unless otherwise noted.

[b] Total dissolved solids reported as wt. %.

APPENDIX K

DESCRIPTION OF STATIC LEACHING EXPERIMENTS WITH REFUSE FROM ILLINOIS BASIN CLEANING PLANT B[a]

Experiment No. SGL-5

Leachate No.	Refuse Size	T, °C	Air	Time (Days)
2	-20 mesh	22	limited	0.01
3	-3/8 in.	22	limited	0.01
4	-20 mesh	22	limited	1
5	-3/8 in.	22	limited	1
6	-20 mesh	22	open	1
7	-3/8 in.	22	open	1
8	-20 mesh	75	open	1
9	-3/8 in.	75	open	1
10	-20 mesh	22	limited	7
11	-3/8 in.	22	limited	7
12	-20 mesh	22	open	7
13	-3/8 in.	22	open	7
14	-20 mesh	75	open	7
15	-3/8 in.	75	open	7
16	-20 mesh	22	limited	28
17	-3/8 in.	22	limited	28
18	-20 mesh	22	open	28
19	-3/8 in.	22	open	28
20	-20 mesh	75	open	28
21	-3/8 in.	75	open	28
22	-20 mesh	22	open	56
23	-3/8 in.	22	open	56

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[a] An average of refuse samples 17, 23, and 24 was used in these studies.

ANALYSES FROM STATIC LEACHING OF REFUSE FROM ILLINOIS BASIN PLANT B

EXPERIMENT No. SGL-5[a]

	Leachate Identification No.										
	2	3	4	5	6	7	8	9	10	11	12
Time (days)	0.01	0.01	1	1	1	1	1	1	7	7	7
pH	2.4	2.5	2.1	2.2	2.2	2.2	2.0	2.1	2.2	2.2	2.0
TDS[b]	0.80	0.38	0.90	0.66	1.05	0.70	1.25	0.85	0.89	0.74	1.15
Na	9.2	7.0	9.0	8.6	12.3	8.7	17.5	8.9	13.4	9.2	9.8
Mg	242	169.9	234.4	214.7	269.9	189.7	257.3	209.1	230.9	220	251.2
Al	817	346	815	528	976	428	911	453	874	481	938
SiO_2											
K	34.6	31.9	13.8	38.9	8.4	31.8	12.7	33.5	72.8	35.7	7.0
Ca	628	453	672	631	809	558	806	641	735	598	759
Sc	1.77	1.42							0.69	1.23	2.0
V	0.84	0.37	1.34	1.04	1.38	0.98	2.10	1.46	1.68	1.42	1.8
Cr(µg/kg)	870	260	770	400	780	300	630	500	690	430	330
Mn	27.5	21.0	27.7	25.5	31.5	21.4	32.9	27.9	28.9	29.9	32.5
Fe	8000	3300	8200	5900	9500	6700	12500	9000	9100	7800	10000
Co	17.9	12.7	18.4	18.3	21.0	15.1	17.7	18.7	17.7	19.7	19.6
Ni	30.2	21.2	28.8	29.7	32.7	28.3	29.2	27.2	27.8	29.3	31.0
Cu	1.7	4.9	0.61	6.0	1.6	3.4	0.24	2.2	0.06	1.3	1.6
Zn	34.8	27.6	43.6	40.4	50.8	31.7	59.1	41.9	51.1	47.9	65.3
Ga	<0.2	<0.2							<0.2	<0.2	<0.2
As	2.99	1.63							3.37	2.11	3.4
Br	<0.04	0.05							<0.04	<0.04	< 0.04
Rb	<8	<8							<8	<8	< 8
Ag	<0.04	<0.04							<0.04	<0.04	< 0.04
Cd(µg/kg)	150	110	160	140	190	120	280	140	160	150	260
Sb	<0.2	<0.2							<0.2	<0.2	<0.2
Cs	<0.16	<0.16							<0.16	<0.16	<0.16
La	<2	<2							<2	<2	1.84
Ce	1.28	0.86							2.25		2.49
Sm	0.47	0.53							0.67		0.58
Eu	0.07	0.06							0.12	0.11	0.14
Tb											
Dy	0.31	0.33	0.49	0.44	0.66	0.55	0.69	1.1	0.78	0.49	0.86
Yb	0.62	<0.12							<0.12	< 0.12	<0.12
Lu	< 0.01	< 0.01							0.02	< 0.01	0.03
Hf	< 0.08	< 0.08							< 0.08	< 0.08	<0.08
Ta	< 0.2	< 0.2							< 0.2	< 0.2	<0.2
W	< 0.04	< 0.04							< 0.04	< 0.04	0.09
Hg	< 1	< 1							< 1	< 1	<1
Pb		2.7	4.3	1.8	1.6	1.5	1.5	1.7	1.5	1.4	1.5
Th	< 0.08	0.53							< 0.08	< 0.08	0.64
U	< 0.24	0.26							0.23	0.37	0.38

---

[a] Elemental concentrations reported as µg/g of refuse unless otherwise noted.

[b] Total dissolved solids reported as wt. %.

ANALYSES FROM STATIC LEACHING OF REFUSE FROM ILLINOIS BASIN PLANT B (Cont.)

EXPERIMENT No. SGL-5[a]

	Leachate Identification No.										
	13	14	15	16	17	18	19	20	21	22	23
Time (days)	7	7	7	28	28	28	28	28	56	56	56
pH	2.1	1.7	1.9	2.5	2.4	1.8	1.9	1.6	1.8	1.7	1.8
TDS[b]	0.83	2.14	1.28	1.22	0.94	2.67	2.17	3.44	2.18	5.10	4.07
Na	9.2	29.6	15.9	26.3	24.5	3.2	10	50.6	29.7	2.4	10.2
Mg	198.1	352.6	300.5	260.0	218.8	261.9	228.8	463.6	407.4	266.5	265.3
Al	319	1628	910	952	545	1070	591	2967	2071	1123	879
SiO_2											
K	19.7	17.9	56.6	204.8	126.8	1.3	1.0	311.7	72.6	2.4	2.7
Ca	688	797	853	784	538	803	535	846	1002	809	1105
Sc	1.50	2.12	1.20								
V	1.43	3.41	1.78	1.95	2.00	2.00	2.09	4.5	3.17	2.48	2.17
Cr(µg/kg)	390	1610	820	800	540	850	580	2840	2210	910	740
Mn	26.0	40.3	35.9	30.7	24.9	39.4	47.2	47.5	54.5	47.7	62.5
Fe	9100	23200	12600	11000	11200	28600	22300	33000	19400	50800	40900
Co	20.5	16.5	18.0	17.9	19.0	20.5	19.7	17.2	21.2	20.9	23.3
Ni	27.4	31.1	32.6	28.5	25.4	35.2	34.9	34.5	38.0	38.0	42.3
Cu	3.5	0.86	1.6	0.15	0.14	10.9	14.3	0.24	3.9	18.5	24.7
Zn	42.1	85.5	57.3	60.9	70.6	93.9	54.3	119.2	69.1	134.3	63
Ga	<0.2	<0.2	<0.2								
As	2.32	5.59	4.93								
Br	<0.04	< 0.04	< 0.04								
Rb	<8	< 8	< 8								
Ag	<0.04	< 0.04	< 0.04								
Cd(µg/kg)	150	280	170	170	140	290	180	310	200	310	220
Sb	<0.2	< 0.2	<0.2								
Cs	<0.16	< 0.16	<0.16								
La	1.82	< 2	0.93								
Ce	2.81	< 0.32	1.58								
Sm	0.43	1.2	0.33								
Eu	0.11	0.15	0.11								
Tb											
Dy	0.73	0.85	0.66	1.15	0.94	0.86	0.86	1.09	0.81	< 0.01	1.57
Yb	<0.12	<0.12	0.20								
Lu	0.04	0.05	<0.01								
Hf	<0.08	<0.08	<0.08								
Ta	<0.2	<0.2	<0.2								
W	<0.04	<0.04	<0.04								
Hg	<1	< 1	<1								
Pb	1.4	1.6	2.2	2.0	4.0	1.4	1.4	1.4	1.1	1.2	1.9
Th	0.48	0.23	<0.08								
U	0.28	0.37	0.27								

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[a] Elemental concentrations reported as µg/kg of refuse unless otherwise noted.

[b] Total dissolved solids reported as wt. %.

APPENDIX L
DESCRIPTION OF CONTINUOUS LEACHING STUDIES OF ILLINOIS BASIN COAL REFUSE[a]

Plant	Experiment No.	Refuse Used[b]	Leachate Flow Pattern
A	GL-19	12, 25, 28	Uninterrupted
B	GL-7	17, 23, 24	Uninterrupted
	GL-8	17, 23, 24	Uninterrupted
	GL-9	17, 23, 24	Interrupted at 2.7 ℓ for 1 day and at 8.7 ℓ for 7 days
	GL-10	17, 23, 24	Interrupted at 2.7 ℓ for 1 day and at 8.7 ℓ for 7 days
C	GL-20	18,19,20,21,22	Uninterrupted

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[a] These experiments were conducted at ambient temperature with 1.5 kg of refuse material crushed to -3/8 in and packed into a 70-cm long by 4.6 cm diam. glass column. Leachate (distilled water) flow rate was maintained at 0.5 mℓ/min.

[b] Refuse sample studied was an average of the listed fractions.

ANALYSES FROM CONTINUOUS LEACHING OF REFUSE FROM ILLINOIS BASIN PLANT A

EXPERIMENT No. GL-19[a]

	Leachate Increment No.							
	1	2	4	7	12	13	19	20
Volume (ℓ)	0.1	0.6	1.3	2.5	6.9	8.1	13.7	14.2
pH	2.9	3.3	4.6	6.0	6.8	7.0	7.5	7.7
TDS[b]	2.72	1.6	0.7	0.4	0.1	0.1	0.06	0.06
Na	63	29	14	3.6	0.71	0.60	0.41	0.38
Mg	650	360	160	80	13	10	4	3
Al	140	82	2	< 1	< 1	< 1	< 1	< 1
K	61	37	20	11	3.6	8.4	1.8	4.3
Ca	610	580	540	600	360	320	150	140
Sc	0.68	0.19	0.01	<0.01	< 0.01	<0.01	< 0.01	< 0.01
V	0.05	0.02	<0.01	<0.01	< 0.01	<0.01	< 0.01	< 0.01
Cr(μg/ℓ)	110	30	30	30	30	30	30	30
Mn	52	29	15	7	0.94	0.68	0.18	0.17
Fe	4100	2070	870	190	5.4	2.4	0.9	0.1
Co	17	10	4	0.7	< 0.05	< 0.05	< 0.05	< 0.05
Ni	27	14	6.5	1.7	0.05	< 0.05	< 0.05	< 0.05
Cu	4.7	1.1	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
Zn	15	7.5	3.2	0.7	0.09	0.08	0.04	0.03
Ga	<0.05	<0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
As	0.16	0.11	0.05	0.01	0.01	< 0.01	< 0.01	0.01
Br	0.07	<0.01	< 0.01	< 0.01	< 0.01	0.01	0.02	< 0.01
Rb	<2	<2	< 2	< 2	< 2	< 2	< 2	< 2
Ag	<0.01	<0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Cd(μg/ℓ)	150	51	11	< 1	< 1	< 1	< 1	< 1
Sb	<0.05	<0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
Cs	<0.04	<0.04	< 0.04	< 0.04	< 0.04	< 0.04	< 0.04	< 0.04
La	0.48	0.25	0.06	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5
Ce	1.66	0.99	0.25	< 0.08	< 0.08	< 0.08	< 0.08	< 0.08
Sm	0.43	0.27	0.04	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02
Eu	0.09	0.05	0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Dy	0.32	0.14	0.04	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Yb	0.11	0.07	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03
Lu	0.02	0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Hf	<0.02	<0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02
Ta	<0.05	<0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
W	<0.01	<0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Hg	<0.25	<0.25	< 0.25	< 0.25	0.02	< 0.25	< 0.25	< 0.25
Pb(μg/ℓ)	120	37	-	33	9	16	< 5	< 5
Th	0.20	0.08	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02
U	0.43	0.16	0.01	< 0.01	0.01	< 0.01	< 0.01	< 0.01

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[a] Elemental concentrations reported as μg/mℓ unless otherwise noted.

[b] Total dissolved solids reported as wt. %.

ANALYSES FROM CONTINUOUS LEACHING OF REFUSE FROM ILLINOIS BASIN PLANT B

EXPERIMENT No. GL-7[a]

	Leachate Increment No.						
	2	7	14	17	29	37	44
Volume (ℓ)	1.2	1.6	3.5	5.3	10.5	15.1	18.3
pH	2.1	1.9	2.3	2.7	2.8	3.0	3.0
TDS[b]	1.19	2.58	0.69	0.11	0.05	0.03	0.02
Na	3.0	6.4	2.3	0.43	0.37	0.27	0.23
Mg	49	120	36	60	24	11	1
Al	122	327	87	8	1.6	< 1	< 1
SiO_2	29	106	64	15	10	10	10
K	8	10	7	2	2	1	1
Ca	146	313	129	21	15	9	6
Sc	<0.01		0.05	0.01	< 0.01		
V	0.35	0.71	0.27	0.06	0.01	0.01	< 0.01
Cr(μg/ℓ)	53	126	46	7.5	0.8	0.4	0.8
Mn	5.8	14.4	4.4	0.7	0.23	0.1	0.1
Fe	1678	3408	1005	159	60	26	24
Co	3.9	8.6	2.5	0.4	0.1	< 0.05	< 0.05
Ni	6.4	13.6	4.3	0.63	0.24	0.06	0.06
Cu	0.7	0.9	< 0.05	< 0.07	< 0.08	< 0.06	< 0.06
Zn	10.6	26.0	8.5	1.3	0.51	0.22	0.17
Ga							
As			0.36	0.39			
Br			0.02	0.04			
Rb							
Ag							
Cd(μg/ℓ)	36	82	28	3.8	1.9	0.7	0.6
Sb							
Cs							
La			0.10				
Ce			0.28				
Sm			0.09				
Eu			0.02				
Tb							
Dy	0.17	0.38	0.12	0.01	< 0.01		
Yb			0.02				
Lu			< 0.01				
Hf							
Ta							
W							
Hg							
Pb(μg/ℓ)	107	53	13	5.8	1.8	0.8	0.2
Th							
U			0.02	0.03			

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[a] Elemental concentrations reported as μg/mℓ unless otherwise noted.

[b] Total dissolved solids reported as wt. %.

ANALYSES FROM CONTINUOUS LEACHING OF REFUSE FROM ILLINOIS BASIN PLANT B

EXPERIMENT No. GL-8[a]

	Leachate Increment No.								
	1	2	3	4	10	16	20	31	38
Volume (ℓ)	0.1	0.2	0.9	2.2	4.4	8.5	11.2	15.2	18.9
pH	1.7	1.7	1.7	2.2	2.6	2.8	3.0	3.1	3.4
TDS[b]	8.1	17.5	3.4	0.64	0.24	0.20	0.37	0.02	0.01
Na	21	35	8	2	0.9	0.3	0.3	0.5	0.2
Mg	368	637	145	35	15	1.5	1.4	1.4	0.6
Al	910	1630	343	69	13	< 1	< 1	< 1	< 1
SiO_2	34	72	66	35	29	12	11	18	8
K	21	38	9	6	5	1.7	1.2	1.7	1.0
Ca	532	904	336	159	48	14	10	11	5
Sc	3.25	6.48	0.92	0.07	< 0.01	<0.01	< 0.01	< 0.01	<0.01
V	1.4	1.16	0.74	0.29	0.07	0.01	0.01	< 0.01	< 0.01
Cr(μg/ℓ)	400	700	132	40	12	0.3	< 0.2	0.3	0.8
Mn	44	75	16	4.5	1.3	0.26	0.19	0.19	0.06
Fe	12000	22100	4750	1020	269	53	37	25	14
Co	28	50	8	2.6	0.6	0.10	0.07	0.06	< 0.05
Ni	43	76	16	4	1	0.25	0.22	0.11	0.06
Cu	8	13	2	0.1	< 0.06	< 0.06	< 0.06	< 0.06	< 0.06
Zn	55	96	26	7.4	2.0	0.38	0.28	0.26	0.08
Ga	< 0.05	< 0.05	< 0.05	< 0.05	<0.05	< 0.05	< 0.05	< 0.05	<0.05
As	7.13	13.4	1.21	0.29	0.05	<0.01	< 0.01	< 0.01	<0.01
Br	1.25	<0.01	<0.01	0.02	0.06	<0.01	< 0.01	< 0.01	<0.01
Rb	<2	<2	<2	<2	<2	<2	< 2	< 2	<2
Ag	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	< 0.01	< 0.01	<0.01
Cd(μg/ℓ)	240	450	92	28	6.5	1.7	1.5	1.0	0.5
Sb	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	< 0.05	< 0.05	<0.05
Cs	<0.04	<0.04	<0.04	<0.04	<0.01	<0.04	< 0.04	< 0.04	<0.04
La	<0.5	2.35	0.40	<0.5	<0.5	<0.5	< 0.5	< 0.5	<0.5
Ce	4.59	5.28	1.47	0.31	<0.08	<0.08	< 0.08	< 0.08	<0.08
Sm	0.46	1.86	0.37	0.04	<0.02	<0.02	< 0.02	< 0.02	<0.02
Eu	0.20	0.37	0.07	0.01	<0.01	<0.01	< 0.01	< 0.01	<0.01
Tb									
Dy	0.69	0.61	0.35	0.14	0.02	<0.01	< 0.01	< 0.01	0.01
Yb	0.44	0.59	0.16	< 0.03	<0.03	<0.03	< 0.03	< 0.03	< 0.03
Lu		0.10	0.02	< 0.01	<0.01	<0.01	< 0.01	< 0.01	< 0.01
Hf	0.05	<0.02	<0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02
Ta	<0.05	<0.05	<0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
W	<0.01	<0.01	<0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Hg	<0.25	<0.25	<0.25	< 0.25	< 0.25	< 0.25	< 0.25	< 0.25	< 0.25
Pb(μg/ℓ)	180	660	85	43	15	7.1	0.2	1.2	0.6
Th	1.45	2.75	0.41	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02
U	0.40	0.77	0.13	0.02	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01

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[a] Elemental concentrations reported as μg/mℓ unless otherwise noted.

[b] Total dissolved solids reported as wt. %.

ANALYSES FROM CONTINUOUS LEACHING OF REFUSE FROM ILLINOIS BASIN PLANT B

EXPERIMENT No. GL-9[a]

	Leachate Increment No.								
	2	7	10	13	19	24	26	32	37
Volume (ℓ)	0.2	1.2	2.5	4.4	6.8	8.2	10.9	16.6	20.5
pH	1.6	2.1	2.4	2.9	2.3	2.6	3.1	3.2	3.4
TDS[b]	8.4	1.2	0.5	0.07	0.40	0.12	0.01	0.01	0.02
Na	17	4.6	1.9	0.41	0.86	0.67	0.16	0.17	0.21
Mg	400	60	27	3.2	13	3.5	0.2	0.2	0.2
Al	1080	129	55	2.2	35	4	< 1	< 1	< 1
SiO_2	140	101	74	21	43	40	3.4	4.5	5.6
K	25	11	7	2.3	3.5	2.7	0.8	0.8	0.8
Ca	579	273	216	32	120	36	3	3	3
Sc	3.32	0.10	0.05	<0.01	0.08	<0.01	<0.01	<0.01	< 0.01
V	1.69	0.56	0.24	0.03	0.13	0.04	< 0.01	< 0.01	0.01
Cr(μg/ℓ)	544	60	27	1.7	17	2.8	< 0.2	< 0.2	< 0.2
Mn	47	7.1	3.1	0.36	1.7	0.48	0.02	0.02	0.02
Fe	12200	1720	821	95	624	195	10	10	10
Co	31	4	1.7	0.17	0.84	0.22	< 0.05	< 0.05	< 0.05
Ni	46	6.6	3.1	0.27	1.7	0.52	< 0.06	< 0.06	< 0.06
Cu	6	0.09	0.10	< 0.05	0.45	< 0.06	< 0.06	< 0.06	< 0.06
Zn	73	43	6.4	0.70	4.5	1.1	0.05	0.05	0.05
Ga	<0.05	<0.05	<0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
As	5.45	0.72	0.21	0.03	0.05	0.08	0.01	0.06	0.06
Br	<0.01	0.03	0.08	0.02	0.01	< 0.01	< 0.01	< 0.01	< 0.01
Rb	<2	<2	<2	<2	< 2	< 2	< 2	< 2	< 2
Ag	<0.01	<0.01	<0.01	<0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Cd(μg/ℓ)	160	46	21	1.8	13	3.1	0.2	1.2	0.3
Sb	<0.05	<0.05	<0.05	<0.05	0.02	<0.05	< 0.05	< 0.05	< 0.05
Cs	<0.04	<0.04	<0.04	0.01	<0.04	<0.04	< 0.04	< 0.04	< 0.04
La	1.55	0.15	<0.5	<0.5	<0.5	<0.5	< 0.5	< 0.5	< 0.5
Ce	4.34	0.48	0.19	<0.08	<0.08	<0.08	< 0.08	< 0.08	< 0.08
Sm	1.05	0.14	0.04	<0.02	0.03	<0.02	< 0.02	< 0.02	< 0.02
Eu	0.30	0.03	0.01	<0.01	< 0.01	<0.01	< 0.01	< 0.01	< 0.01
Tb									
Dy	1.38	0.37	0.09	< 0.01	0.05	0.01	<0.01	< 0.01	< 0.01
Yb	0.44	0.03	0.02	< 0.03	< 0.03	<0.03	<0.03	< 0.01	< 0.03
Lu	0.05	0.01	<0.01	< 0.01	< 0.01	<0.01	<0.01	< 0.01	<0.01
Hf	<0.02	<0.02	< 0.01	< 0.02	< 0.02	<0.02	<0.02	< 0.02	<0.02
Ta	<0.05	<0.05	< 0.05	< 0.05	< 0.05	<0.05	<0.05	< 0.05	<0.05
W	<0.01	<0.01	< 0.01	< 0.01	< 0.01	<0.01	<0.01	< 0.01	<0.01
Hg	<0.25	<0.25	< 0.25	< 0.25	< 0.25	<0.25	<0.25	< 0.25	<0.25
Pb(μg/ℓ)	410	50	11	8.8	3.9	5.4	9.4	0.5	1.8
Th	1.60	<0.02	< 0.02	< 0.02	< 0.02	<0.02	<0.02	< 0.02	<0.02
U	0.41	0.03	0.01	< 0.01	0.02	< 0.01	< 0.01	< 0.01	

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[a] Elemental concentrations reported as μg/mℓ unless otherwise noted.

[b] Total dissolved solids reported as wt. %.

ANALYSES FROM CONTINUOUS LEACHING OF REFUSE FROM ILLINOIS BASIN PLANT B

EXPERIMENT No. GL-10[a]

	Leachate Increment No.										
	2	3	6	7	10	12	16	20	22	24	28
Volume (ℓ)	0.3	1.5	2.6	3.3	5.2	7.2	9.1	10.4	11.0	12.1	18.5
pH	1.7	1.6	2.6	2.4	2.7	3.0	2.3	2.5	2.8	2.7	3.3
TDS[b]	6.8	6.9	0.2	0.4	0.1	0.1	0.6	0.1	0.1	0.06	0.02
Na	14	15	5.2	2.3	0.9	0.5	1.1	0.3	0.2	0.4	0.1
Mg	353	753	10	17	4	2	16	1.9	0.9	1.3	0.1
Al	988	946	10	37	2.7	1.4	58	2.5	< 1	< 1	< 1
SiO_2	163	40	37	55	40	27	55	19	9		2.5
K	24	22	6	7	2.7	2.7	3.1	2.0	1.3	1.8	0.6
Ca	578	971	98	136	29	16	120	14	6.7	8.5	2.5
Sc	2.2	2.7	< 0.01	0.07	<0.01	<0.01	0.24	<0.01	< 0.01	<0.01	< 0.01
V	2.94	2.63	0.11	0.18	0.04	0.02	0.18	0.03	0.01	0.02	< 0.01
Cr(µg/ℓ)	506	510	8	17	0.7	< 0.2	22	0.5	< 0.2	< 0.2	< 0.2
Mn	42	41	1.1	2.2	0.49	0.27	2.6	0.29	0.12	0.20	0.01
Fe	10800	11100	286	553	134	78	987	120	55	87	9
Co	27	27	0.60	1.2	0.23	0.11	1.2	0.15	0.08	0.08	< 0.05
Ni	41	42	1.1	2.1	0.41	0.14	2.4	0.25	0.13	0.13	0.06
Cu	3	8	< 0.07	0.5	< 0.07	< 0.07	1.1	< 0.07	< 0.07	< 0.07	< 0.07
Zn	61	56	2.0	4.1	0.93	0.49	4.4	0.54	0.24	0.35	0.03
Ga	<0.05	<0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
As	<0.01	<0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Br	<0.01	<0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Rb	<2	<2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2
Ag	<0.01	<0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Cd(µg/ℓ)	240	240	5.1	11	2.4	1.2	1.3	1.3	0.6	0.9	0.4
Sb	<0.05	<0.05	<0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
Cs	<0.04	<0.04	<0.04	< 0.04	< 0.04	< 0.04	< 0.04	< 0.04	< 0.04	< 0.04	< 0.04
La	1.5	1.3	<0.5	< 0.5	< 0.5	< 0.5	0.5	< 0.5	< 0.5	< 0.5	< 0.5
Ce	2.8	2.7	<0.08	< 0.08	< 0.08	< 0.08	0.3	< 0.08	< 0.08	< 0.08	< 0.08
Sm	1.1	0.3	0.02	< 0.02	< 0.02	< 0.02	0.06	< 0.02	< 0.02	< 0.02	< 0.02
Eu	0.18	0.17	< 0.01	< 0.01	< 0.01	< 0.01	0.01	< 0.01	< 0.01	< 0.01	< 0.01
Tb											
Dy	1.1	0.9	0.1	0.1	0.1	0.01	0.1	0.01	0.01	< 0.01	< 0.01
Yb	0.3	< 0.03	<0.03	< 0.03	< 0.03	< 0.03	0.03	< 0.03	< 0.03	< 0.03	< 0.03
Lu	0.04	0.03	<0.01	< 0.01	< 0.01	< 0.01	0.01	< 0.01	< 0.01	< 0.01	< 0.01
Hf	<0.02	< 0.02	<0.02	< 0.02	< 0.02	< 0.02	<0.02	< 0.02	< 0.02	< 0.02	< 0.02
Ta	<0.05	< 0.05	<0.05	< 0.05	< 0.05	< 0.05	<0.05	< 0.05	< 0.05	< 0.05	< 0.05
W	<0.01	< 0.01	<0.01	< 0.01	< 0.01	< 0.01	<0.01	< 0.01	< 0.01	< 0.01	< 0.01
Hg	<0.25	< 0.25	<0.25	< 0.25	< 0.25	< 0.25	<0.25	< 0.25	<0.25	< 0.25	< 0.25
Pb (µg/ℓ)	360	280	18	13	6.6	7.7	7.0	2.0	2.5	5.3	2.4
Th	0.9	1.3	<0.02	< 0.02	< 0.02	< 0.02	0.07	< 0.02	<0.02	< 0.02	< 0.02
U	0.3	0.4	< 0.01	0.01	< 0.01	< 0.01	0.03	< 0.01	< 0.01	< 0.01	< 0.01

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[a] Elemental concentrations reported as µg/mℓ unless otherwise noted.

[b] Total dissolved solids reported as wt. %.

ANALYSES FROM CONTINUOUS LEACHING OF REFUSE FROM ILLINOIS BASIN PLANT C

EXPERIMENT No. GL-20[a]

	Leachate Increment No.				
	1	3	5	8	11
Volume (ℓ)	0.1	0.8	1.2	3.0	5.4
pH	2.4	2.6	2.8	3.5	3.8
TDS[b]	3.1	1.6	1.2	0.1	0.1
Na	3300	1600	1030	63	
Mg	290	140	122	12	6
Al	41	38	10	4	0.7
K	99	68	61	17	9
Ca	610	440	490	150	110
Sc	1.42	0.75	0.16	< 0.01	< 0.01
V	0.49	0.21	0.12	< 0.01	< 0.01
Cr (μg/ℓ)	1040	510	150	< 10	< 20
Mn	26	14	11	1	0.5
Fe	2870	1570	1250	130	56
Co	17.4	8.9	7.2	0.6	0.2
Ni	26.4	13.7	10.6	1	0.4
Cu	1.6	0.44	< 0.05	< 0.05	< 0.05
Zn	10	5	5	0.5	0.3
Ga	<0.05	<0.05	< 0.05	< 0.05	< 0.05
As	0.69	0.15	0.10	0.04	0.03
Br	<0.01	<0.01	0.11	< 0.01	< 0.01
Rb	3.1	<2	< 2	< 2	< 2
Ag	<0.01	<0.01	< 0.01	< 0.01	< 0.01
Cd (μg/ℓ)	160	72	38	2	0.8
Sb	<0.05	<0.05	< 0.05	< 0.05	< 0.05
Cs	<0.04	<0.04	< 0.04	< 0.04	< 0.04
La	1.16	0.92	0.62	0.02	< 0.5
Ce	4.47	3.72	2.58	0.15	< 0.08
Sm	0.92	0.71	0.44	0.01	< 0.02
Eu	0.16	0.13	0.09	< 0.01	< 0.01
Dy	0.58	0.35	0.21	< 0.01	< 0.01
Yb	0.19	0.14	0.07	< 0.03	< 0.03
Lu	0.03	0.02	0.01	< 0.01	< 0.01
Hf	<0.02	<0.02	< 0.02	< 0.02	<0.02
Ta	<0.05	<0.05	< 0.05	< 0.05	< 0.05
W	0.2	<0.01	< 0.01	< 0.01	< 0.01
Hg	<0.25	< 0.25	< 0.25	<0.25	< 0.25
Pb (μg/ℓ)	150	68	27	< 2	< 4
Th	1.2	0.6	0.1	<0.02	<0.02
U	0.65	0.41	0.18	<0.01	<0.01

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[a] Elemental concentrations reported as μg/mℓ unless otherwise noted.

[b] Total dissolved solids reported as wt. %.

APPENDIX M

DESCRIPTION OF STATIC LEACHING EXPERIMENTS WITH COAL FROM ILLINOIS BASIN CLEANING PLANT E[a]

Experiment No. SCL-1

Leachate No.	Refuse Size	T, °C	Air	Time (Days)
1/2[b]	-20 mesh	22	Limited	0.01
3	-20 mesh	22	Limited	0.01
4	-3/8 in.	22	Limited	0.01
5	-20 mesh	22	Limited	1
6	-3/8 in.	22	Limited	1
7A	-20 mesh	75	Open	1
8A	-3/8 in.	75	Open	1
9	-20 mesh	22	Open	1
10	-3/8 in.	22	Open	1
11/12[b]	-20 mesh	22	Limited	7
13	-20 mesh	22	Limited	7
14	-3/8 in.	22	Limited	7
15	-20 mesh	75	Open	7
16	-3/8 in.	75	Open	7
17	-20 mesh	22	Open	7
18	-3/8 in.	22	Open	7
19/20	-20 mesh	22	Limited	14
21/22[b]	-20 mesh	22	Limited	28
23	-20 mesh	22	Limited	28
24	-3/8 in.	22	Limited	28
26	-3/8 in.	75	Open	28
27	-20 mesh	22	Open	28
28	-3/8 in.	22	Open	28

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[a] An average of coal samples 36 and 37 was used in these studies. Wet coal sample used unless indicated.

[b] Coal sample dried at 60°C before leaching.

ANALYSES FROM STATIC LEACHING OF PLANT E ILLINOIS BASIN COAL

EXPERIMENT No. SCL-1[a]

	Leachate Increment No.													
	1[c]	2[c]	3	4	5	6	7A	8A	9	10	11[c]	12[c]	13	14
Time (Days)	0.01	0.01	0.01	0.01	1	1	1	1	1	1	7	7	7	7
pH	5.3	5.4	3.5	3.0	3.2	3.4	3.7	2.6	3.1	2.9	4.9	4.8	3.3	3.1
TDS[b]	0.06	0.06	0.25	0.37	0.31	0.21	0.81	0.34	0.27	0.28	0.12	0.12	0.43	0.35
Na	70	70	24	12	20	23	29	35	20	54	75	75	14	42
Mg	30	30	50	30	55	30	55	45	50	45	40	40	55	45
Al	<6	<6	56	25	50	12	53	34	52	29	<6	<6	62	28
K	20	20	1.4	1.0	0.6	3.8	7.7	6.3	1.5	8.8	27	27	0.4	2.9
Ca	415	415	755	595	1065	605	1055	470	1055	570	830	815	1020	825
Sc	<0.01	<0.01	0.18	0.24	0.25	0.11	0.19	0.10	0.23	0.09	<0.01	<0.01	0.06	0.12
V	<0.07	<0.07	<0.07	0.07	0.07		0.46	0.35	0.09	0.24	<0.07<	0.07	0.46	0.24
Cr(μg/kg)	30	35	100	120	90	90	180	160	100	150	50	60	130	140
Mn	5	5	13	8	16	10	20	12	17	10	10	10	18	14
Fe	21	27	1270	1820	1090	1060	4100	2480	1100	1800	120	140	2590	2220
Co	5	5	7.0	5	8.0	7	10	7	9.0	7.0	7	7	11	8
Ni	10	10	16	10	19	12	21	13	17	12.0	13	14	22	14
Cu	<0.01	<0.01	0.63	1.4	0.42	0.5	0.44	0.37	0.10	0.15	<0.01	<0.01	<0.1	0.75
Zn	1.2	1.1	7.2	5.0	9.1	4.9	12.5	7.5	9.1	6.6	1.9	1.9	11.6	9.1
Ga	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
As	<0.02	<0.02	0.04	2.51	0.12	<0.02	1.64	1.58	0.07	0.15	<0.02	<0.02	0.22	0.17
Br	<0.04	<0.04	0.05	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	0.08	<0.04	<0.04	<0.04	0.06
Rb	<8	<8	<8	<8	<8	<8	<8	<8	<8	<8	<8	<8	<8	<8
Ag	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
Cd(μg/kg)	20	20	50	60	70	70	10	60	70	50	25	25	70	50
Sb	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
Cs	<0.16	<0.16	<0.16	<0.16	<0.16	<0.16	<0.16	<0.16	<0.16	<0.16	<0.16	<0.16	<0.16	<0.16
La	<2	<2	<2	<2	<2	<2	2.7	<2	<2	<2	<2	<2	<2	<2
Ce	<0.32	<0.32	<0.32	<0.32	<0.32	<0.32	<0.32	<0.32	<0.32	<0.32	< 0.32	<0.32	<0.32	0.65
Sm	<0.08	<0.08	0.22	0.43	0.45	<0.08	0.37	<0.08	0.36	<0.08	< 0.08	<0.08	0.31	0.23
Eu	<0.05	<0.05	0.06	0.11	0.11	0.05	0.07	0.07	0.08	0.05	<0.05	<0.05	0.08	0.09
Dy	<0.01	<0.01		0.28	0.58	0.34	0.55	0.69	0.52	0.56	<0.01	<0.01	0.60	0.28
Yb	<0.12	<0.12	<0.12	0.11	0.16	<0.12	0.37	<0.12	0.19	<0.12	<0.12	<0.12	<0.12	0.13
Lu	<0.01	<0.01	0.01	0.03	<0.01	0.02	0.03	<0.01	0.01	<0.01	<0.01	<0.01	0.03	0.02
Hf	<0.08	<0.08	<0.08	<0.08	<0.08	<0.08	<0.08	<0.08	<0.08	<0.08	<0.08	<0.08	<0.08	<0.08
Ta	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
W	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
Hg	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Pb	0.58	0.45	0.19	0.70	0.99	0.93	0.63	0.36	0.42	0.41	0.56	0.41	0.36	0.51
Th	<0.08	<0.08	<0.08	<0.26	<0.08	<0.08	<0.08	<0.08	<0.08	<0.08	<0.08	<0.08	<0.08	<0.08
U	0.1	0.01	0.12	0.17	0.25	0.33	1.89	0.24	0.26	0.11	0.06	0.02	0.20	0.15

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[a] Elemental concentrations reported as μg/g of refuse unless otherwise noted. Wet coal leached unless noted.

[b] Total dissolved solids reported as wt. %.

[c] Dried coal used.

ANALYSES FROM STATIC LEACHING OF PLANT E ILLINOIS BASIN COAL (Cont.)

	EXPERIMENT No. SCL-1[a] Leachate Increment No.											
	15	16	17	18	19/20	21[c]	22[c]	23	24	26	27	28
Time (Days)	7	7	7	7	14	28	28	28	28	28	28	28
pH	2.3	2.5	2.6	2.6	3.5	4.8	4.9	2.9	3.4	2.3	2.1	2.1
TDS[b]	1.22	0.46	0.58	0.23	0.45	0.12	0.12	0.48	0.38	0.53	1.53	0.92
Na	64	39	4	32	14	80	80	9	62	72	2	46
Mg	80	55	45	30	55	40	45	55	50	80	50	50
Al	125	56	75	25	54	6	<6	94	35	169	155	75
K	36.3	10.6	1.0	1.2	1.6	30	30	12.5	21.8	28.8	0.8	1.1
Ca	202	530	820	370	988	825	775	940	565	745	835	255
Sc	0.31	0.17	0.39	0.14		<0.01	<0.01			0.23		0.33
V	1.34	0.48	0.23	0.13	0.43	<0.07	<0.07	1.11	0.88	1.22		0.99
Cr(μg/kg)	230	190	150	140	140	70	70	200	200	260	230	270
Mn	24	13	17	10	17	11	11	18	14	17	25	25
Fe	7500	3180	3260	1950	2755	300	300	3150	3420	5550	16440	10060
Co	12	7	9.0	7.0	10	7	7	10	5	6	12	8.0
Ni	24	13	17	14	19	14	14	19	14	15	27	18.0
Cu	0.36	0.75	0.15	0.14	<0.1	<0.01	<0.01	0.20	<0.1	0.69	0.23	0.27
Zn	19.4	6.9	10.9	4.1	11.9	3.2	2.9	14.1	5.4	8.8	21.6	7.2
Ga	<0.2	<0.2	<0.2	<0.2		<0.2	<0.2		<0.2	<0.2		<0.2
As	7.66	2.09	2.20	0.64		<0.02	<0.02		4.06	3.10		8.86
Br	<0.04	<0.04	<0.04	<0.04		<0.04	0.1		<0.04	<0.04		<0.04
Rb	<8	<8	<8	<8		<8	<8		<8	<8		<8
Ag	<0.04	<0.04	<0.04	<0.04		<0.04	<0.04		<0.04	<0.04		<0.04
Cd(μg/kg)	90	60	70	40	70	35	30	80	50	70	110	50
Sb	<0.2	<0.2	<0.2	<0.2		<0.2	<0.2		<0.2	<0.2		<0.2
Cs	<0.16	<0.16	<0.16	<0.16		<0.16	<0.16		<0.16	<0.16		<0.16
La	<2	0.69	0.93	0.65		<2	<2		<2	<2		<2
Ce	<0.32	<0.32	<0.32	<0.32		<0.32	<0.32		<0.32	<0.32		0.44
Sm	0.32	0.23	0.26	0.29		<0.08	<0.08		<0.08	0.24		0.25
Eu	0.13	0.10	0.10	0.06		<0.05	<0.05		0.05	0.10		0.07
Dy	0.86	0.50	0.34	0.66	0.51	0.05	0.09	0.68	0.57	0.98		0.46
Yb	<0.12	<0.12	<0.12	0.08		<0.12	<0.12		<0.12	<0.12		0.12
Lu	0.03	0.02	0.16	0.03		<0.01	<0.01		<0.01	<0.01		0.02
Hf	<0.08	<0.08	<0.08	<0.08		<0.08	<0.08		<0.08	<0.08		<0.08
Ta	<0.2	<0.2	<0.2	<0.2		<0.2	<0.2		<0.2	<0.2		<0.2
W	<0.04	<0.04	<0.04	<0.04		<0.04	<0.04		<0.04	<0.04		<0.04
Hg	<1	<1	<1	<1		<1	<1		<1	<1		<1
Pb	0.43	0.45	0.48	0.48	0.52	0.44	0.44	0.36	0.59	0.50	0.37	0.66
Th	<0.08	<0.08	0.16	0.13		<0.08	<0.08		<0.08	<0.08		0.32
U	0.25	0.16	0.24	0.28		0.09	0.03		0.06	0.13		0.16

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[a] Elemental concentrations reported as μg/g of refuse unless otherwise noted. Wet coal leached unless noted.

[b] Total dissolved solids reported as wt. %.

[c] Dried coal used.

APPENDIX N

DESCRIPTION OF CONTINUOUS LEACHING STUDIES OF COAL FROM ILLINOIS BASIN CLEANING PLANT E[a,b]

Experiment No.	Leachate Flow Pattern
CL-5	Interrupted at 0.4ℓ for 1 day
	Interrupted at 1.4ℓ for 1 day
	Interrupted at 2.2ℓ for 1 day
	Interrupted at 3.8ℓ for 2 days
	Interrupted at 4.8ℓ for 2 days
	Interrupted at 7.4ℓ for 7 days
CL-6	Interrupted at 0.8ℓ for 1 day
	Interrupted at 1.3ℓ for 2 days
	Interrupted at 2.8ℓ for 1 day
	Interrupted at 4.8ℓ for 2 days
	Interrupted at 7.1ℓ for 2 days
	Interrupted at 10.1ℓ for 6 days
CL-7	Uninterrupted
CL-8	Uninterrupted

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[a] These experiments were conducted at ambient temperature with 0.95 kg of coal material crushed to -3/8 in. and packed into a 70-cm-long by 4.6-cm-diam glass column. Leachate (distilled water) flow rate was maintained at 0.5 ml/min.

[b] An average of coal samples 36 and 37 was used in these studies.

ANALYSES FROM CONTINUOUS LEACHING OF ILLINOIS BASIN PLANT E COAL

EXPERIMENT No. CL-5[a]

	Leachate Increment No.									
	2+3	6+7	8+9	13+14	22+23	29+30	34+35	39+40	44+45	46+47
Volume (ℓ)	0.2	0.9	1.2	2.1	4.5	5.2	7.0	8.2	8.6	11.5
pH	2.2	2.4	2.6	2.9	2.8	2.7	3.2	2.2	2.4	3.1
TDS[b]	3.76	1.45	0.70	0.24	0.08	0.12	0.04	0.41	0.31	0.02
Na	25	14	6	2	2	2	2	2	3	1
Mg	87	45	17	4	0.5	0.5	0.14	1	1	0.04
Al	125	59	22	4	1.5	1.5	< 0.7	7	4	< 0.6
K	0.9	1	2.5	4	1	0.9	1	0.8	3	0.9
Ca	515	400	470	305	81	92	14	130	110	3
Sc	0.445	0.19	0.06	0.01	< 0.01	0.01	< 0.01	0.04	0.01	<0.01
V	0.58	0.40	0.18	0.03	< 0.01	0.01	< 0.01	0.08	0.07	< 0.01
Cr(μg/ℓ)	144	66	25	4	< 3	< 3	< 3	7	4	< 3
Mn	22	10	5	1	0.2	0.4	0.07	1	0.9	0.02
Fe	5240	2420	940	200	31	100	15	640	470	11
Co	9.4	4.7	1.8	0.4	0.09	0.09	< 0.07	0.2	0.2	< 0.06
Ni	17	9	4	0.7	0.1	0.2	< 0.07	0.6	0.4	< 0.06
Cu	4.8	2.6	0.9	0.2	0.2	0.2	0.02	1.6	0.3	< 0.02
Zn	13	7	3	0.56	0.11	0.17	< 0.02	0.57	0.44	< 0.02
Ga	0.07	<0.05	<0.05	<0.05	<0.05	<0.05	< 0.05	< 0.05	< 0.05	< 0.05
As	6.64	1.25	0.25	0.01	< 0.01	0.03	0.02	0.75	< 0.01	< 0.01
Br	< 0.01	< 0.01	< 0.01	<0.01	0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Rb	< 2	< 2	< 2	<2	< 2	< 2	< 2	< 2	< 2	< 2
Ag	< 0.01	< 0.01	< 0.01	<0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Cd(μg/ℓ)	70	48	23	8	2	2	0.5	10	9	< 0.2
Sb	< 0.05	< 0.05	< 0.05	<0.05	< 0.05	< 0.05	< 0.05	0.03	< 0.05	< 0.05
Cs	< 0.04	< 0.04	< 0.04	<0.04	< 0.04	< 0.04	< 0.04	< 0.04	< 0.04	< 0.04
La	0.80	0.18	< 0.5	<0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5
Ce	1.38	0.35	0.15	<0.08	< 0.08	< 0.08	0.02	< 0.5	< 0.5	< 0.5
Sm	0.35	0.20	0.09	0.03	< 0.02	< 0.02	< 0.02	0.04	0.02	< 0.02
Eu	0.11	0.05	0.02	0.01	< 0.01	< 0.01	< 0.01	0.01	0.01	< 0.01
Dy	0.66	0.43	0.20	0.05	0.01	0.02	< 0.01	0.10	0.05	< 0.01
Yb	0.20	0.05	< 0.03	<0.03	< 0.03	< 0.03	< 0.03	0.02	< 0.03	< 0.03
Lu	0.02	0.01	< 0.01	<0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Hf	< 0.02	< 0.02	< 0.02	<0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02
Ta	< 0.05	< 0.05	< 0.05	<0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
W	< 0.01	< 0.01	< 0.01	<0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Hg	< 0.25	< 0.25	< 0.25	<0.25	< 0.25	< 0.25	< 0.25	< 0.25	< 0.25	< 0.25
Pb(μg/ℓ)	15	24	8	9	9	2	0.7	< 2	5	< 2
Th	0.34	0.10	0.04	<0.02	< 0.02	< 0.02	< 0.02	0.04	< 0.02	<0.02
U	0.22	0.09	0.04	0.01	< 0.01	< 0.01	< 0.01	0.03	0.01	< 0.01

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[a] Elemental concentration reported as μg/mℓ unless otherwise indicated.

[b] Total dissolved solids in wt. %.

ANALYSES FROM CONTINUOUS LEACHING OF ILLINOIS BASIN PLANT E COAL

EXPERIMENT No. CL-6[a]

	Leachate Increment No.										
	4+5	10+11	14+15	19+20	27+28	31+32	35+36	39+40	44+46	48+49	51+52
Volume (ℓ)	0.2	0.7	1.3	2.2	6.1	7.1	7.7	9.0	10.8	11.1	13.6
pH	2.1	2.3	2.5	2.8	3.0	3.0	2.8	3.3	2.2	2.4	3.2
TDS[b]	2.50	1.73	0.64	0.20	0.05	0.05	0.09	0.31	0.44	0.31	0.02
Na	20	11	2	2	1	1	2	1	1.5	2	1
Mg	78	39	17	4	0.3	0.2	0.5	0.1	1	0.93	0.05
Al	113	52	22	4.5	0.7	< 0.7	1	0.7	9	5	< 0.7
K	0.7	2	0.9	2	0.6	0.7	0.8	1	0.8	2.7	1
Ca	480	440	330	200	35	20	57	12	115	110	2
Sc	0.42	0.17	0.10	0.01	0.01			< 0.01	0.04	0.01	
V	0.79	0.41	0.20	0.03	< 0.01	< 0.01	0.01	< 0.01	0.07	0.07	< 0.01
Cr(μg/ℓ)	230	52	21	5	< 3.5	< 3.5	< 3.5	< 3.5	12.5	6.3	< 3.5
Mn	70	10.5	4	1	0.09	0.1	0.25	0.07	1.5	1.1	0.02
Fe	4830	2310	950	220	22	6	96	17	680	530	10
Co	9	4	2	0.35	< 0.07	< 0.07	0.07	< 0.07	0.23	0.17	< 0.07
Ni	16	8	4	0.7	0.07	< 0.07	0.15	< 0.07	0.6	0.46	< 0.07
Cu	5	2	1	0.3	0.11	< 0.02	0.05	0.02	1.7	0.56	< 0.02
Zn	12	6	3	0.7	0.07	0.05	0.15	< 0.02	0.6	0.46	< 0.02
Ga	<0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	-
As	< 0.01	<0.01	<0.01	<0.01	< 0.01	<0.01	<0.01	< 0.01	<0.01	<0.01	-
Br	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	< 0.01	<0.01	<0.01	-
Rb	<2	<2	1.11	<2	<2	<2	<2	< 2	<2	<2	-
Ag	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	< 0.01	<0.01	<0.01	-
Cd(μg/ℓ)	91	52	20	5	2	0.5	1	0.3	9	5	0.2
Sb	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	< 0.05	<0.05	<0.05	-
Cs	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	0.04	< 0.04	<0.04	<0.04	-
La	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	< 0.5	<0.5	<0.5	-
Ce	0.68	0.41	<0.08	<0.08	<0.08	<0.08	<0.08	< 0.08	<0.08	<0.08	-
Sm	0.34	0.22	0.08	<0.02	<0.02	0.01	<0.02	< 0.02	<0.02	< 0.02	-
Eu	0.09	0.05	0.02	< 0.01	<0.01	<0.01	<0.01	< 0.01	0.01	< 0.01	-
Dy	0.72	0.39	0.21	0.06	0.01	< 0.01	0.01	< 0.01	0.10	0.06	<0.01
Yb	0.22	0.07	0.04	< 0.03	<0.03	<0.03	<0.03	< 0.03	0.03	< 0.03	-
Lu	0.03	0.01	0.01	< 0.01	<0.01	<0.01	<0.01	< 0.01	<0.01	< 0.01	-
Hf	<0.02	<0.02	<0.02	< 0.02	<0.02	<0.02	<0.02	< 0.02	<0.02	< 0.02	-
Ta	<0.05	<0.05	<0.05	< 0.05	<0.05	<0.05	<0.05	< 0.05	<0.05	< 0.05	-
W	<0.01	<0.01	<0.01	< 0.01	<0.01	<0.01	<0.01	< 0.01	<0.01	< 0.01	-
Hg	<0.25	<0.25	<0.25	< 0.25	<0.25	<0.25	<0.25	< 0.25	<0.25	< 0.25	-
Pb(μg/ℓ)	61	16	45	15	4	4.5	52	7	6	8	20
Th	0.32	0.06	0.05	< 0.02	<0.02	<0.02	0.01	< 0.02	0.04	< 0.02	-
U	0.18	0.09	0.05	0.01	0.01	< 0.01	0.01	< 0.01	0.03	0.01	-

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[a] Elemental concentrations reported as μg/mℓ unless otherwise indicated.

[b] Total dissolved solids reported as wt. %.

ANALYSES FROM CONTINUOUS LEACHING OF ILLINOIS BASIN PLANT E COAL

EXPERIMENT No. CL-7[a]

	Leachate Increment No.									
	2+3	9+10	12+13	14+15	17+18	19+20	32+33	44+45	56+57	62+63
Volume (ℓ)	0.2	0.5	1.0	1.9	2.5	3.1	7.0	10.2	15.0	20.5
pH	2.2	2.3	2.4	2.9	3.1	3.2	3.3	3.6	3.5	3.9
TDS[b]	2.94	1.74	1.02	0.21	0.10	0.07	0.03	0.02	0.02	0.02
Na	29	16	10	2	1.5	1	2	2	2	1
Mg	93	52	30	5	1.5	0.8	0.2	0.09	0.1	0.07
Al	125	75	38	5	1	< 0.7	< 0.7	< 0.7	< 0.7	< 0.7
K	5.5	0.5	0.8	1.5	6	0.9	0.75	0.5	4.5	1
Ca	500	470	420	260	160	135	32	9	9	5
Sc	0.42	0.20	0.07	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	-
V	0.58	0.32	0.32	0.04	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	
Cr(μg/ℓ)	150	60	34	4	< 3.5	< 3.5	< 3.5	< 3.5	< 3.5	< 3.5
Mn	23	14	8	2	0.5	0.2	0.1	0.02	0.05	0.02
Fe	5800	3120	2430	260	70	37	2	2	0.7	2
Co	10	5.6	3.2	0.5	0.2	0.09	< 0.08	< 0.08	< 0.08	< 0.08
Ni	18	11	6	1	0.3	0.2	< 0.08	< 0.08	< 0.08	< 0.08
Cu	6	2	1	0.05	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02
Zn	13	8	5	0.8	0.2	0.1	0.03	< 0.02	< 0.02	< 0.02
Ga	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.01	< 0.05	-
As	< 0.01	< 0.01	< 0.01	< 0.01	0.02	< 0.01	< 0.01	< 0.01	< 0.01	-
Br	0.03	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	-
Rb	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	-
Ag	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	-
Cd(μg/ℓ)	83	71	38	13	2	1	1	0.3	0.2	1
Sb	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	-
Cs	< 0.04	< 0.04	< 0.04	< 0.04	< 0.04	< 0.04	< 0.04	< 0.04	< 0.04	-
La	0.54	< 0.5	0.13	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	-
Ce	0.57	0.37	< 0.08	< 0.08	< 0.08	< 0.08	< 0.08	< 0.08	< 0.08	-
Sm	0.28	0.30	0.16	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	-
Eu	0.09	0.06	0.04	0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	-
Dy	0.64	0.38	0.31	0.06	0.01	< 0.01	< 0.01	< 0.01	< 0.01	-
Yb	0.20	0.10	0.05	0.01	< 0.03	< 0.03	<0.03	<0.03	<0.03	-
Lu	0.01	0.02	0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	<0.01	-
Hf	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	<0.02	-
Ta	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.01	<0.05	-
W	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	<0.01	-
Hg	< 0.25	< 0.25	< 0.25	< 0.25	< 0.25	< 0.25	< 0.25	< 0.25	<0.25	-
Pb(μg/ℓ)	45	13	15	5	5	< 2	< 2	2	5	2
Th	0.38	0.09	0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	<0.02	-
U	0.18	0.11	0.07	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	-

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[a] Elemental concentrations reported as μg/mℓ unless otherwise indicated.

[b] Total dissolved solids reported as wt. %.

ANALYSES FROM CONTINUOUS LEACHING OF ILLINOIS BASIN PLANT E COAL

EXPERIMENT No. CL-8[a]

	Leachate Increment No.								
	2+3	6+7	11+12	13+14	15+16	20+21	37+38	50+51	58+59
Volume (ℓ)	0.2	1.1	1.3	1.6	2.8	4.4	9.6	15.9	20.2
pH	2.3	2.5	2.7	2.9	3.2	3.3	3.2	3.5	3.7
TDS[b]	3.87	0.80	0.58	0.40	0.07	0.03	0.03	0.01	0.2
Na	29	6	5	4	1	1	2	1	2
Mg	92	21	14	9	1	0.3	0.3	0.07	0.07
Al	126	29	17	10	0.9	< 0.7	< 0.7	< 0.7	< 0.7
K	0.5	0.95	0.7	2	2	2	1	0.5	2
Ca	460	450	445	370	140	32	24	4	5
Sc	0.16	0.02	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	-	-
V	0.54	0.25	0.15	0.07	< 0.01	< 0.01	< 0.01		
Cr(μg/ℓ)	146	25	13	6.5	< 3.5	< 3.5	<3.5	<3.5	<3.5
Mn	25	6	4	3	0.4	0.09	0.1	< 0.02	< 0.02
Fe	7160	1240	760	265	44	9	4	0.3	0.2
Co	11	2.5	1.4	1	1	< 0.07	< 0.07	< 0.07	< 0.07
Ni	20	5	3	2	2	0.07	0.07	< 0.07	< 0.07
Cu	5.5	0.7	0.2	0.05	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02
Zn	14	3.5	2	1.5	0.16	0.07	0.04	< 0.02	< 0.02
Ga	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.03	-	-
As	< 0.01	0.14	0.14	0.05	< 0.01	< 0.01	< 0.01	-	-
Br	< 0.01	< 0.01	< 0.01	< 0.01	0.01	< 0.01	< 0.01	-	-
Rb	< 2	< 2	< 2	< 2	< 2	< 2	< 2	-	-
Ag	< 0.01	< 0.01	< 0.01	< 0.01	<0.01	< 0.01	< 0.01	-	-
Cd(μg/ℓ)	76	23	13	12	0.9	0.3	2	0.8	0.1
Sb	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	-	-
Cs	< 0.04	< 0.04	< 0.04	< 0.04	< 0.04	< 0.04	< 0.04	-	-
La	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	-	-
Ce	< 0.08	< 0.08	< 0.08	< 0.08	< 0.08	< 0.08	< 0.08	-	-
Sm	0.10	0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	-	-
Eu	0.04	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	-	-
Dy	0.62	0.26	0.27	0.12	0.01	< 0.01	< 0.01	-	-
Yb	0.04	< 0.03	0.02	< 0.03	< 0.03	< 0.01	< 0.03	-	-
Lu	0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	-	-
Hf	<0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	-	-
Ta	<0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	-	-
W	<0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	-	-
Hg	<0.25	< 0.25	< 0.25	< 0.25	< 0.25	< 0.25	< 0.25	-	-
Pb(μg/ℓ)	30	14	< 2	10	< 2	9	13	< 2	< 2
Th	0.15	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	-	-
U	0.18	0.03	0.02	0.01	< 0.01	< 0.01	< 0.01	-	-

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[a] Elemental concentrations reported as μg/mℓ unless otherwise noted.

[b] Total dissolved solids reported as wt. %.

TECHNICAL REPORT DATA

(Please read Instructions on the reverse before completing)

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16. ABSTRACT The report describes the results to date of research to assess the potential pollution by trace elements discharged from coal storage piles and coal cleaning wastes. Mineralogic and trace element analyses on raw coal and coal wastes from three Illinois Basin preparation plants have been completed. Static and dynamic aqueous leaching studies to determine the release potential of pollutants from coals and coal cleaning wastes have also been completed. Based on their toxicity and leachability, the nine trace elements of primary environmental concern are F, Al, Mn, Fe, Co, Ni, Cu, Zn, and Cd.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS		b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group	
Pollution Trace Elements Coal Coal Dust Coal Storage Wastes	Coal Preparation Leaching Toxicity Chemical Analysis Properties	Pollution Control Stationary Sources Characterization	13B 06A 21D 08I	 07D,07A 06T

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